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FABRICATION AND TEST OF A SPACE POWER BOILER FEED ELECTROMAGNETIC PUMP

III - Endurance and Final Performance Tests

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16. Abstract

A three phase helical induction electromagnetic pump designed for the boiler-feed pump of a potassium Rankine Cycle space power system was developed and built. It was then mounted in a liquid metal test loop and successfully tested over a range of potassium temperatures from 900° to 1400° F, flow rates from 0.75 to 4.85 lb/sec, developed pressures up to 340 psi, net positive suction head (NPSH) from 1 to 22 psi, and NaK coolant temperatures from 800° to 950° F. Maximum efficiency at design point conditions of 3.25 lb/sec flow rate, 240 psi developed head, 1000° F potassium inlet temperature, and 800° F NaK coolant inlet temperature was 16.3 percent. After the performance tests the pump was operated without any difficulty at design point for 10,000 hours, and then a limited number of repeat performance tests were made. The conclusion reached is that there was no appreciable change in the pump performance after 10,000 hours of operation. A supplementary series of tests using the quasi-square wave power output of a DC to 3 phase AC inverter showed the pump would operate without difficulty at a frequency as low as 25 Hz, with little loss in efficiency.

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I. SUMMARY

The General Electric Company, under Contract NAS 3-9422, has completed the design, building, performance and endurance testing of an electromagnetic pump for use as a boiler feed pump in a potassium Rankine cycle space electrical power system. The pump has a design flow rate of 3.25 lb/sec at a developed head of 240 psi, when pumping potassium at a temperature of 1000°F.

This report (Part III of three parts) describes the endurance test over a period of 10,000 hours, along with the final performance tests, some of which were made with a quasi-square wave power supply from a DC to AC inverter. Part I of the report described the pump design, fabrication, and assembly. Part II covered the design and fabrication of the test facility, along with the extensive performance test series prior to start of the endurance test program.

The endurance test at design point conditions, initiated immediately after completion of the first performance tests, was continued for 10,000 hours with only a few short pauses to check or maintain facility items. There was essentially no change in performance over the period of the test. Calculated efficiency stayed between 16 and 16.5%, with no indication of pump wear or deterioration.

Following the endurance tests, a limited number of performance tests at 45, 85, and 135 volts with a 60 Hz sine wave provided data that, when plotted as curves, fell above on top of the original performance curves.

To obtain further important test data, an inverter was built to provide a 3 phase quasi-square wave at the same three test voltages,

but at 25, 45, and 60 Hz, from a DC motor generator source. The results indicated that the pump operated without difficulty at all test frequencies but with lower efficiency than with the sine wave power at 60 Hz. However, the efficiency at low voltage and 25 Hz was above the 60 Hz value.

II INTRODUCTION

On the basis of the Electromagnetic Pump design study under NASA Contract NAS 3-8500, a flight type pump was built for Rankine cycle boiler feed applications, to meet the following specifications.

	Design Point	Off-Design Range
Potassium Temperature, °F	1000	900 - 1400
K Flow Rate, lb/sec	3.25	0.75 - 4.25
Pressure Rise, psi	240	35 - 300
NPSH, psi	7	1 - 22
NaK Coolant Temperature, °F	800	700 - 900
Voltage, V	135	30 - 165

As described in Part I of this report, the pump included T-111 alloy for the duct, with bimetal transition joints for welding into the test loop which was made of austenitic stainless steel. The pump stator, with a Hiperco 27 magnetic structure, Ni clad Ag conductors, and high purity alumina or "S" glass tape insulation included a cooling section through which NaK is circulated.

The wide range of test conditions specified, required that a facility be provided for comprehensive control of all parameters and extensive instrumentation output. The facility to accomplish the testing is described in Part II of this report, which also includes the results of the comprehensive performance tests and comparisons with the expected performance, calculated during the design study.

This report (the last Part of the complete Final Report) reviews the pump performance over the endurance test period of 10,000 hours and then presents data from a final series of performance tests at 45, 85, and 135 volts with standard sine wave power to obtain a comparison with the original data. In addition, results of analysis of the liquid metals are provided to indicate the negligible effects of the long time operation on the K and NaK being circulated.

The 10,000 hour test of the pump, added to the nearly 1000 hours of performance test operation, demonstrated the reliability of the electromagnetic design of pump for handling 1000°F potassium at high pressure and limited flow. No design or operation problems were encountered which would preclude the building and application of the basic helical three phase induction configuration for a wide range of temperatures and flows, especially for high developed pressure applications.

A series of tests using quasi-square wave power produced by a solid state inverter provided data on the pump performance at 60, 45, and 25 Hz. The pump operated without any problems, and the data indicated the pump was capable of providing good flow and pressure over the range of frequencies and with the relatively poor power wave shape.

III ENDURANCE TEST

Immediately after completing the extensive series of performance tests, design point conditions were established on the test pump and the endurance test was initiated. The Endurance Test Plan (included as Appendix A) specified the following test conditions:

Potassium flow, lb/sec	3.25 ± 0.30
Potassium inlet temp., °F	1000 ± 15
Potassium inlet pressure, psia	8 ± 1
Pressure rise, psi	240 ± 6
NaK inlet temp., °F	800 ± 10
NaK outlet temp., °F	850 ± 10

In accordance with the test plan the pump and test loop were periodically checked during each day, and minor adjustments made where necessary to maintain the test conditions. Generally the only adjustment found necessary was the air to the K and NaK coolers. The air supply, which came from the plant system varied some with the time of day (load on system and number of compressors in service). However, the power supply voltage remained constant within about ± 1% so that no adjustment was generally needed. The throttle valve as well as other remote controlled valves were operated from the shop air supply, but regulators in the feed lines kept the low pressures very constant.

Three times a day (once each shift) the various important facility items listed in the form attached to the test plan (Figure A-2 of Appendix A) were checked and signed off. Once each day a full set of data point readings was obtained by one of the test men, who was especially trained to operate the facility, after observing that the various valves were constant for a period of 15 minutes and recorded on a data form (Figure A-1).

A. REVIEW OF DATA

Table I shows important basic data that was collected each day, along with the calculated power factor and efficiency. The data was also used to plot "step" curves to show the results and trends during the overall tests. These curves are included as Figure 1. Note that the trend of efficiency was upward. The average after test E-44 was 16.00%, and for the entire 10,000 hours was 16.27%.

A copy of the actual data sheet showing the results after 160 hours of operation is included as Figure 2. A copy of the data sheet taken after 9544 hours of operation is included in this report as Figure 3. Both sets of data were taken by the same operator, and conditions were essentially the same although the position of valve VML-1 would indicate a slight difference in the flow of K through the hot trap by-pass.

B. LIQUID METAL CHARACTERISTICS

Both the potassium and the NaK in the test loops was sampled and analyzed at the conclusion of the performance tests and just as the endurance tests were initiated. Subsequently the K was sampled while the loop was in operation, and data obtained after 500, 1000, 2000, 3000, 4000, 5000, 6000, and 10,000 hours. The NaK sample could be obtained only when the coolant loop was "dumped", so a sample was taken at shut-downs which occurred at 3036 and 10,000 hours of operation. Analysis information on all the samples is included in Table II.

Samples of NaK and K removed from the EM pump loop were analyzed for oxygen and carbon, and at specified times for metallic impurities. Oxygen is determined by dissolving an aliquot of the sample alkali metal in mercury, allowing the resulting oxides to separate, and stripping residual liquid metal from the separated oxides by repeated extractions with fresh mercury. The NaK and K oxides are measured by titrating the alkalinity produced on dissolution of the oxide residue in distilled water.

Carbon is determined by high temperature combustion of an aliquot of the liquid metal in a quartz system. The evolved CO_2 is condensed in a liquid nitrogen cooled trap and subsequently measured by gas chromatography.

Metallic impurities in the liquid metals are determined by emission spectroscopy on the alkali metal chlorides prepared by reacting an aliquot of liquid metal with ethanol, acidifying with HCl and evaporating the acidified solution to dryness.

C. PUMP PARAMETERS - RESISTANCE AND PRESSURE

Two conditions or parameters of the pump were periodically checked to determine if there was appreciable or meaningful changes during the endurance test. These were the pump winding resistance (phase to phase - terminal to terminal) and resistance to ground, plus the pressure of the argon in the duct and stator cavities. A summary of the data obtained is shown in Table III.

The resistance and pressure data was obtained each time as soon as possible after the pump was stopped and de-energized, so as to correlate with the various temperature values (windings especially). A Rubicon portable Wheatstone Bridge was used for the winding resistance measurements (which are less than 1 ohm) and lead resistance was checked and subtracted from each reading. The bridge was checked with a General Radio 1 ohm standard with an error of less than 0.003%. Winding resistance to ground was measured with a Megger (50 V scale) when it was high enough to use this instrument, or with a Simpson volt-ohmist when the resistance was below 0.5 megohms. Final (room temperature) resistances were checked with a Kelvin Bridge and firmly attached leads.

Pressure of the pump duct cavity was continuously monitored by a transducer which was connected through its own amplifier and output meter for a highly accurate measurement, to a meter relay for daily recording and alarm purposes. The stator cavity pressure was checked by determining the contact closing position of the pressure switch which had been calibrated prior to installation and was also connected to the "low pressure" alarm system. The stator cavity pressure measurement accuracy was approximately ±1 psi, while the duct cavity pressure measurement accuracy was approximately ± 0.1 psi.

D. DISCUSSION

This review and discussion of the endurance test results will cover the operation in general, and then specifically comment on the resistance changes that were noted, for this is the only area that showed any effect from the 10,000 hour test.

Endurance Test - General

The results of the daily data measurements as shown in Table I and, as plotted as curves in Figure 1, clearly indicate that there was no significant change in performance over the 10,000 hour period. The very slight trend (generally upward) in efficiency could have been due to changes in the wattmeter, for although it was rechecked and found to be within tolerance limits at the 3000 hour point, the calculated efficiency is directly dependent on a consistant reading and a change of only 1% will change the efficiency by the same amount. Of course, the hydraulic power varies with flow and pressure, and directly affects the efficiency calculations, but the recorders for these values were checked monthly and showed essentially no change. Therefore a small change in the wattmeter performance is most likely to be the cause of the slight efficiency improvement.

Overall, the endurance test was highly satisfactory, and there was no indication from the daily results that there would be any change in another 10,000 hours.

Cavity Pressures

Final pump stator and duct cavity pressure showed a very slight increase during the 10,000 hours. This would appear to indicate very limited outgassing may have taken place after the cavities were baked-out, filled with argon to approximately 8 psia at room temperature and sealed. However, there were no leaks from the pinch-off seals, for the cavities had about 21 psia pressure in them during the endurance test when the temperature in the cavities was at about 1000°F. The results are particularly interesting as far as the stator cavity is concerned for there was a great volume of insulating material in this area which might have outgassed during the endurance test period.

Winding and Ground Resistance

The resistance measurements provided the most noticeable change in conditions, not in the winding resistance but in the resistance to ground (a measure of the insulation resistance). The winding resistances T_{1-2}, T_{2-3}, T_{3-1} in Table III) were essentially unchanged (within the limits of careful measurement at comparable temperatures). As the pump windings were connected in "Y" with the common point floating, the actual value of any one set of coils (line to common) is half of the tabulated value. The final value, accurately measured at room temperature, was 0.046 ohms. This compares with measured values during a shut down in the initial performance testing of 0.049 ohms (and original assembly check when cold, of 0.039 to 0.046 ohms), obtained with a slightly less accurate low resistance measuring instrument.

The insulation resistance, or at least the resistance measurement between the windings and ground, became of some concern during the endurance test. A review of the results of tests at final pump assembly indicated there had been some indication that the measured resisitance of more than

100 meg ohms with a 500 V megger was once or twice momentarily unstable and of lower value. However, after installation the resistance value was very high (1600 meg-ohms) and testing was initiated. Subsequently, as indicated in Table III, the resistance to ground varied each time it was checked (under high temperature conditions) but the trend was to lower values, and to less than 1 meg-ohm so that the megger could not generally be used to obtain a reading.

Of course a major reason for the low resistance during normal operation is the reduction in specific resistance of the ceramic slot insulation (10^{12} Ω cm at room temperature versus 10^{8} Ω cm at 1200^{o}F). A total slot liner area of 1012 sq. in. and 0.038 in. thick insulation would show a change in resistance from 8850 meg-ohms to 442K ohms.

During the endurance test there were occasional indications of a momentary grounding of a single point in the windings. A special ground detector circuit was set up to monitor the pump condition because the pump windings were not grounded, even though connected in "Y". An artificial neutral point was established by connecting three AC voltmeters in "Y" with the center point attached to ground through a 10V meter and limiting resistor. Thus a ground on the winding would cause the neutral voltmeter to show a reading and the phase voltmeters to change from their balanced condition. A recording voltmeter provided a continuous record of the ground condition.

While the grounding condition occurred in a random pattern, and would (at least initially) clear itself promptly, there were times late in the endurance test when the ground persisted. At those times the pump was disconnected from the power system and a high voltage (300 to 400V) 60 Hz limited current (to 5A) source was applied momentarily between a pump terminal and ground. This invariably eliminated the ground and resistance-to-ground measure 200K to 400K ohms.

However, shortly after the final performance test was completed, while operating at design conditions and waiting for completion of the inverter for tests described in Section V of this report, there was an indication of very low resistance to ground. A check showed essentially zero ohms, and that the condition (as in all previous similar situations) was present in one phase only. Overall operation of the pump was not affected by this condition (power input, efficiency, etc. remained unchanged) but a limited risk was involved because of the possibility of an internal short circuit if another phase became grounded, and the ground could not be cleared as before.

Final resistance checks at room temperature showed that a ground of relatively low resistance (about 0.005 ohms at room temperature) was definitely present from the winding connected to T_2. It is suspected that the ground has occurred across the edge of one piece of the ceramic which lines the slots, because the conductor is not insulated at the point where it exits from the slot. It is also possible that the track, or low resistance path, may have been initiated by a small metal "whisker" that became lodged in this area during assembly, and many heating and cooling cycles caused it to move and start a "bridging" action.

Liquid Metal Characteristics

As described in Part II of this Final Report, special care was taken to clean the test loops and fill with highly refined and pure liquid metal. The good results from this careful preparation and metal handling is evident in a review of the analysis data shown in Table II.

During the 10,000 hours of endurance testing there was essentially no change in the amount of oxygen, carbon, or various metallics in either the potassium or NaK. The oxygen content of the potassium of 4 to 11 ppm is not a meaningful amount, and the carbon content actually decreased. The oxygen in the NaK was a little higher than in the K, but it actually decreased during the more than 400 days of testing. All values are well below the specified maximums for the testing program.

IV FINAL PERFORMANCE TEST WITH 60 Hz SINE WAVE POWER

Immediately following the completion of the 10,000 hour endurance test, a limited program was conducted to recheck some of the "off-design" conditions that were explored during the initial performance tests (Refer to Part II of this Final Report). The schedule for the series of final performance tests, with 60 Hz sine wave "shop" power (the same as used for the original performance tests) is shown as part of the Test Plan, included in this report as Appendix B.

A. TEST PLAN AND TEST PROCEDURE

During the performance testing each specified test condition was established by making the following adjustments:

- Set specified pump voltage
- Adjust throttle valve for specified K flow
- Adjust K and NaK air coolers to obtain specified inlet temperature
- Adjust NaK flow as required to obtain specified NaK ΔT.

Prior to recording any data, all temperatures were observed for a period of 15 minutes, during which all values were to remain within specified tolerances.

B. TEST RESULTS

All final performance test results are tabulated in Table IV. The information provides all important data for drawing performance curves and for comparison with the initial performance test series. It will be noted that the test plan schedule was amplified slightly by adding tests to check out minimum controllable flow/maximum pressure conditions at the lower voltages.

Figure 4 is a plot of the test data for the standard conditions of temperature, and at 135 volts which is very close to the design point setting (about 131 volts as noted in data from the endurance test). Similar data but for 85 and 45 volt power input settings are included in Figures 5 and 6. Additional information for comparison purposes is shown by the curves in Figures 7, 8 and 9 for Pressure, Power, and Efficiency versus Flow at the three test voltages (135, 85 and 45 volts). Figure 10 shows the performance data in the final tests compared with the original design calculated data of expected results.

C. DISCUSSION OF RESULTS

A review of the curves showing final pump performance indicates the results are consistent and typical of what was to be expected. Furthermore, a comparison with curves drawn from the original performance data indicates the final results are essentially right on top of the original curves, except that the power input tends to be slightly lower at lower flows and efficiency a little higher at the "middle" flow conditions (1.5 to 3 lb/sec). This could be due to a slight drift in the wattmeter output readings, although within tolerance limits.

During the final performance test series, two test conditions were added to the total (FP-3A and FP-11A) to check maximum flow at 135 volts, and minimum controllable flow at 45 V. Information on Figures 4, 5, and 6 indicate this additional and useful information. In conducting these (extreme condition) tests it was found that the pump flow was easy to control right down to the point when the throttle valve closed and maximum pressure was obtained. The test facility performed extremely well throughout the tests and contributed to the ease with which the full range of flow data could be obtained.

Figure 10 includes curves showing power input, pressure developed, and efficiency, for the 135 volt setting and design point K and NaK temperatures, during the final tests as well as the original calculated (expected performance). This comparison serves to summarize and emphasize several important points.

First, the pump that has been designed and tested for 10,000 hours is on order of magnitude better in efficiency than previously built pumps of similar ratings. A recent report by the Oak Ridge National Laboratory[(1)] on performance of a helical induction pump with duct made of T-111, pumping potassium at 1215°F, showed a maximum efficiency of 2.1% with a flow of 0.4 lb/sec (as compared to the maximum flow rating of 0.6 lb/sec). Obviously the pump tested at ORNL was considerably smaller than the boiler feed pump, but the efficiency of over 16% obtained with the boiler feed pump which has been on endurance test indicates that major strides have been made in improving the EM pump performance.

Second, several supplementary water flow tests on the boiler feed pump duct and a model duct, indicated the efficiency could be improved by possibly as much as 5% (or 0.8 percentage points) through a reversal in the K flow direction. Some limited tests on the actual duct just before assembly provided pressure drop data as follows:

[(1)] Young, H.C. and Clark, D.L., "Hydraulic Performance and Cavitation Characteristics of am EM Helical Induction Pump Operating with Potassium and Prediction of Performance with Lithium at 2200°F," ORNL-TM-2995, November 1970.

Pressure Drop (Design Direction of Flow) = 38 psi

Pressure Drop (Flow Reversed) = 29.5 psi

Results: An indicated reduction of 29% in pressure drop with flow reversed.

Similar but more comprehensive data was obtained through a series of tests at NASA-LeRC using an aluminum model of the pump duct. This test is covered in a separate report which is summarized in this Final Report, Part III, as Appendix C.

The data from the NASA-LeRC tests showed that the difference in pressure drop through the duct was about 28% when the results from the flow in the design direction was compared with the flow reversed. This compares quite favorably with data obtained with the actual duct and described above, where a reduction of 29% was obtained.

V. PERFORMANCE TEST WITH QUASI-SQUARE WAVE

A number of possible space power systems will have DC or high frequency AC as the power source output. This means that an EM pump, such as the boiler feed pump that has been described in this report, which requires a relatively low frequency power source, must obtain it from the primary source through an inverter.

In order to obtain some previously unavailable data, an inverter has been designed and built to accept a DC input and provide a low frequency quasi-square wave output in the range of 25 to 60 Hz. The boiler feed pump was then performance tested with the inverter power supply to obtain data with voltage input conditions that were the same as used for the final performance test with the 60 Hz sine wave power, and reported in Section IV on this Final Report, Part III.

This section will describe the inverter that was developed for the tests, and the testing that was conducted in accordance with the Test Plan which is included in this report as Appendix B.

A. INVERTER DESIGN AND HARDWARE

The boiler feed pump requires, for maximum output permitted by the test facility at 135 volts, a 3 phase (rms) current of at least 180 amperes. These values established the size of the SCR's which were to provide the output power, as well as the necessary diodes and switching inductance and capacitance. Input power was to be furnished by a motor-generator set which had a DC generator with a rated output of 250 volts, 300 amperes.

The basic circuit selected for the inverter is described in Appendix D and shown in Figure D-1. It is a typical three phase inverter but uses a common input-commutation circuit. In the circuit operation the four auxiliary (commutating) SCR's are fired in pairs, in an alternating fashion, to turn off those main SCR's which are connected to one or the other side of the DC bus and are conducting at that moment.

The firing of the 10 main SCR's (4 commutating and 6 phase outputs) is controlled by a logic circuit (operating from pulses provided by an oscillator at 3 times the final frequency). This logic circuit is discussed in detail in Appendix D, and shown in Figure D-2. The output pulses go to "pre-driver" transistors for amplification and then to the "driver" board. The "driver" board further amplifies the pulse power to provide adequate drive for the large SCR gates.

The main SCR's, rated 235 amperes rms, 400V PIV, require a firing pulse of (preferably) about 20 volts and more than 2 amperes for at least 10 microseconds. Surety of the turn-on is obtained by multiple pulses, applied during the time the SCR is to be on.

The overall inverter with related power supplies is shown by the block diagram in Figure 11. The lower signal levels in the logic circuitry are carefully remoted from any upsetting (electrically) influence and the logic output pulses control two stages of transistor amplification before the signal (at about 24V) is taken to the SCR gate driver circuit. Signals are carried to the pulse transformers at the main SCR's by twisted shielded cables.

B. FACILITY ARRANGEMENT

The overall set-up for the pump test is shown in Figure 12. The main power unit with the SCR's and diodes mounted on heat sinks, all on a steel frame work, is located behind the table on which is placed the driver/transistor circuit enclosure (front left) and the logic control (in the aluminum enclosure to the right of the driver unit). Power supplies, line voltmeter, and a terminal board for the current transformer (C.T.) outputs, are all placed on the table. The line current transformers are visible at the left, in front of the power conditioner which is located behind the table. The instrument type C.T.'s had a 1000:5 ratio, and a 1 ohm resister was placed across the secondary to provide a voltage trace of the phase current for the oscilloscope input.

A closer view of the inverter is provided by Figure 13, in its location just outside the pump test loop enclosure. The 3 phase power leads go off to the left, through the C.T.'s and into the enclosure (also visible in Figure 12). The incoming DC power from the motor-generator set comes through the fused disconnect switch on the enclosure well, to the bank of Askarel filled capacitors, and then to the inverter. The 25 μfd commutating capacitor is in the box to the right of the inverter.

Figure 14 shows the test pump (insulated) in the center of the picture, taken through the open doors of the enclosure. The special connections for the inverter tests, made with 4/0 cable are visible below the pump. The box with the bus and fuses contains the capacitors for power factor correction, used only for the 60 Hz sine wave tests. On the floor to the left of the capacitor box are the 3 pole fused switches used for selecting shop power or the inverter source for operating the pump. This arrangement permitted rapid change-over during the testing period.

No changes were needed at the control console (described in Part II of this Final Report) to make the quasi-square wave tests. The wattmeter, voltmeter and ammeter were thermocouple instruments and provided rms values, even though the wave shape was distorted. However, the C.T.'s were standard power units and may have had some effect on the measured current and wattmeter values.

C. TEST PLAN

The specific procedures that were followed in setting up the quasi-square wave performance tests, and basic test point conditions to be determined, are given in the Performance Test Plan, Parts III and IV, included in this Final Report (Part III) as Appendix B. During the testing, each specified condition was established by making the following adjustments:

a. Energize inverter at desired frequency and set AC voltage by adjusting DC input voltage.

b. Adjust throttle valve for specified K flow

c. Adjust K and NaK air coolers to obtain standard input temperatures

d. Adjust NaK flow for proper ΔT

Prior to recording the test data, all temperatures were checked to make sure there was no appreciable change over the preceeding 15 minutes.

D. TEST RESULTS AT 45, 85 and 135 VOLTS

A summary of the performance test data obtained during operation with the inverter is given in Table V. The information includes all data needed to prepare the curves showing the performance of the pump. It will be noted that a number of test points, in addition to those listed in the test plan, were checked and data obtained to more fully provide information on operation of the pump with the inverter power supply. For example, maximum possible flow values, along with maximum pressures at no flow (except with higher voltages) were determined.

Figures 15, 16 and 17 show the performance data for the 45, 85, and 135 volt, 60 Hz conditions. Figures 18 and 19 show the results for 45 volts, at 45 and 25 Hz. Finally, Figures 20, 21 and 22 compare pressure, power and efficiency versus flow, with 60 Hz sine wave power and quasi-square wave power.

Some inverter and pump performance variation was observed when the DC line capacitor was changed in value, especially at the higher frequency. A maximum of 1080 μfd was used for all the 60 and 25 Hz tests, but only 600 μfd was used for the initial 45 Hz series due to malfunctions with 3 capacitors (1080 μfd). Subsequently other tests were made with other capacitor valves to provide 600 μfd (2 capacitor units) and 300 μfd (1 capacitor unit) across the input line. Data from all the extra tests is also included in Table 5, with data points plotted in Figures 23 and 24.

During the testing with quasi-square wave power, oscilloscope trace pictures were taken of line current wave shapes at certain test conditions. The trace was driven by the voltage across a 1 ohm resistor which was connected to the secondary terminals of the line (instrument type) current transformers. The ratio was 1000 to 5, so 100 amps in the line produced 0.5 amps in the secondary, resulting in a voltage of 0.5 volts across the 1Ω resistor. Figures 25 and 26 are reproductions of the wave shapes of 60, 45 and 25 Hz test conditions.

E. DISCUSSION

The discussion concerning performance of the pump with the power conditioner will be presented in two parts. First, with reference to the inverter operation, and second, concerning the pump operation with the various frequencies, voltages, and modifications to the inverter input power.

1. Inverter

The inverter operates very well at all three fixed output frequencies (25, 45 and 60 Hz) provided the capacitor bank which was across the DC input line is within certain limits. This capacitor, used to reduce "spikes" of voltage which are generated by the power SCR switching, was initially established with a value of 1080 μfd. Askarel filled units were used because of large currents being handled by the bank.

With the full bank of 3 capacitors (1080 μfd) the inverter operated very well with the full test voltage range (up to 142 volts) at 60 Hz. Performance was also satisfactory at 25 Hz and up to 85 volts, the highest tested. However, at 45 Hz the inverter shorted when even the lowest DC input voltage was applied.

With a reduced bank of 2 capacitors (600 μfd), the inverter furnished power without difficulty at 25 and 45 Hz, but with the control set for 60 Hz the inverter shorted out when output was initiated.

When the input line capacitor was changed to one unit (300 μfd), the inverter satisfactorily supplied power at all frequencies at 45 and 85 volts. However, at 135 volts 60 Hz the operation was marginal; twice the inverter shorted out after carrying the pump load for 10 to 15 minutes and conditions had nearly settled down. Thus the data obtained in this test (CP-14A) was not included in Table V, but indicated a very low efficiency and developed pressure, as compared with the results recorded for test CP-14 and the full bank of input capacitors.

The photographs of oscillope traces taken during certain of the tests at 60 Hz indicate the effect of the input capacitors on the output current wave shape. Referring to Figure 25, it will be noted that with the 1080 μfd bank, the wave shape is relatively smooth. However, with only 300 μfd the wave becomes very ragged and apparently is much less effective in operating the pump. It is also obvious that more harmonic current is flowing which affects the performance of the iron and the interaction may be the reason why the shorting occurred after a limited period of time and the pump windings and core had reached higher temperatures.

Similar effects at 25 Hz and 45 Hz are observable in the current traces shown in Figure 26, as the input capacitor value is changed from 1080 or 600 to 300 μfd. However, the effect at 25 Hz is not very great.

The shorting of the inverter did not damage any of the components. However, high DC current was flowing during the shorted period which if it was not promptly removed by manually tripping the motor-generator output contactor, was cleared by melting of the 300 ampere line fuses. It is suggested that the shorting involved a failure of the power SCR's to be "commutated off", due to the circuit conditions being incompatible with the dv/dt characteristics of the SCR's. Then because the SCR's did not turn off, input line current was flowing through all of them in parallel and the m-g set output under short circuit conditions (with the several hundred feet of cable between m-g set and inverter) was not high enough to exceed the SCR short time current ratings.

Further analysis and investigation of the effect of the input line capacitor size is needed to determine the mechanism of the operating failure experienced, and to determine safe parameters for the circuit components.

2. Pump Performance

Actual pump performance with quasi-square wave power from the inverter, is shown by the curves in Figures 15, 16, 17 (for 60 Hz), 18 (for 45 Hz) and 19 (for 25 Hz). The 60 Hz curves are similar to those obtained for sine wave power and provided in Figures 4, 5 and 6. A comparison of the pump performance with the two types of input power at 60 Hz is given by the curves in Figures 20, 21 and 22. These show that in all cases the performance is poorer with quasi-square wave power. With 135 volts and design point flow (3.25 lb/sec) pressure is down 20% (from 250 to 200 psi), power input is down 4.3 KW or 19%, although efficiency is down only 1.5 points (from 16.2 to 14.7), a change of 9.3%. It was not possible to operate the pump on a high enough voltage from the inverter to reproduce the design point of 3.25 lb/sec flow and 240 psi developed pressure.

Similar comparisons of performance at lower voltages and frequency show similar (though not as drastic) reductions. At 85 volts and a (maximum efficiency) flow of 2.5 lb/sec, the pressure is down from 112 to 89 psi (or 20%), power input down from 9.5 to 8.2 KW (or 14%) although efficiency is down only from 13.2 to 12.2% (or 8%). At 45 volts and a flow of 1.5 lb/sec, pressure is down 18% (from 38 to 31 psi), power input from 3.0 to 2.5 KW (or 16%) but efficiency is down only 2.5% (from 8.6 to 8.4%). These trends are all in line with expected performance, although the relatively minor change at the lower voltages is a little surprising.

The limited number of tests at 25 and 45 Hz provided additional interesting data. Figures 23 and 24 compare these two frequencies with results at 60 Hz with power input at 45 and 85 volts. Some additional data on these curve sheets for various values of input line capacitance will also be discussed.

At 85 volts input (Figure 24), the few test points obtained at this voltage at lower (than 60 Hz) frequencies (when the current increased appreciably due to pump reactance values), pressure and efficiency was always less than the 60 Hz values (when full capacity was connected to the D.C. input power). However, with reduced capacitance (300 μfd) on the input line the data indicates pressure and efficiency are higher at 25 and even 45 Hz than the results from the one test at 60 Hz with 300 μfd.

A greater volume of data was obtained with 45 volts input at the three frequencies so that data is more meaningful. Referring to Figure 23, both efficiency and pressure are higher at the lower flows with the 25 Hz quasi-square wave power than with 60 Hz from the same source. This is true whether or not the input line capacitance is 1080 or 300 μfd. At 45 Hz, which could only be obtained with 600 or 300 μfd, the pressure and effiency were both lower than the 25 Hz values but higher than the 60 Hz values. Thus the overall data indicates that at lower voltages and flows the lower frequency results in better pump performance (but not at higher flows or voltages). This result was anticipated because at low flow, pump slip increases with reduced frequency providing for more efficient use of electrical input power.

Photos of certain oscilloscope traces show line current, in Figures 25 and 26, and also indicate why the pump performed better with the larger bank of capacitors across the input line. The current wave, and thus effective power, was definitely smoother at the higher frequencies (60 and 45 Hz). At 25 Hz there was less difference in the wave shapes with different input capacitor valves although the difference was still noticeable.

One other item that may have affected the results is the instrumentation. The wattmeter, voltmeter, and ammeter were thermocouple instruments and capable of providing a true rms output reading. However, while the voltage was read directly from the line, the current was read through commercial type current transformers. The poor wave shape and harmonics in the line could very well not have been fully passed through those C.T.'s and therefore the rms current value was on the low side with efficiency showing higher than actual.

VI. CONCLUSIONS

The electromagnetic boiler feed pump has been successfully operated for a total of more than 10,000 hours at design point conditions, pumping 1000°F potassium with a flow rate of 3.25 lb/sec, a pressure rise of 240 psi, and power at approximately 132 volts, while the stator was being cooled with 800°F NaK. Average efficiency during this extensive period of time was 16.27%.

During the endurance test, the only interruptions in continuous operation were required for facility maintenance, and this time amounted to only a few days in total. No shut downs were the result of a failure in the pump although the limited change noted in resistance of the coils to ground would appear to warrant investigation as to the reason, and methods for improvements. However, as the plot of efficiency over the entire period (refer to Figure 1) indicates, there was no detectable deterioration in the pump performance and no reason to believe it could not have continued in operation for another 10,000 hours.

At the conclusion of the endurance test, the series of performance tests served to confirm the general conclusion that there was no change in the pump operating characteristics. The results, as shown by the curves plotted from the test data, indicate no noticeable deviation from the curves obtained prior to the endurance test. The final data curves fall right on top of the original test data curves! Furthermore, within the limits of the test facility it was possible to raise pump pressure (by closing the throttle valve) until the flow actually stopped, but the pump operation was smooth and steady right up to the limit.

Operation of the pump at lower frequencies (25 to 45 Hz) using a quasi-square wave power source was successfully conducted, providing data showing reliable operation at these "off design" conditions. At 60 Hz with the quasi-square wave power, pump performance was good, but not comparable to the sine wave power.

Overall, the pump and test facility operated in a very satisfactory manner, especially with sine wave power. Pump output was easy to control, and the facility permitted easy and prompt adjustment of such parameters as flow, pressure, and temperature.

The pump gave somewhat poorer performance using quasi-square wave power than sine wave power. The quasi-square wave forms were quite "ragged" and sensitive to the amount of capacitance used across the input DC line to the inverter. In order to achieve the maximum pump efficiency in future space systems, it will be necessary to carefully match inverter output and pump to achieve optimum wave shapes for the best pumping.

APPENDIX A

ENDURANCE TEST PLAN

I. INTRODUCTION

This test plan specifies the endurance test conditions and data which is to be obtained, while the pump is operating for a period of 10,000 hours, after it has successfully completed the performance test program.

II. GENERAL

Endurance testing will be performed with the facility essentially unattended, after an initial period of operation demonstrates that the pump and facilities will operate over a period of time within acceptable fluctuations (limits) but no basic adjustments of flow, heaters, etc.

Endurance test conditions are as follows:

1. Potassium flow - 3.25 lb/sec, ± 0.3 lb/sec
2. Potassium inlet temperature - 1000^{o}F, ± 15^{o}F
3. Potassium inlet pressure - 8 psia, ± 1 psia
4. Potassium discharge pressure - 248 psia, ± 6 psia
5. NaK inlet temperature - 800^{o}F, ± 10^{o}F
6. NaK outlet temperature - 850^{o}F, ± 10^{o}F

III. INSTRUMENTATION AND CALIBRATION

Prior to start of the endurance test, calibrate all pressure transducer outputs and check flow meter in the potassium loop against the orifice.

All temperature recording instruments will be checked on a monthly schedule in accordance with NSP instructions.

IV. TEST RECORDING AND MONITORING

The test will operate without constant attendance by a technician, but with the following schedule of inspection and data taking.

1. Once each day a complete set of performance data will be recorded on Form NS-1304 (Figure A-1) and checked with previous data sheets to determine any variations. An out-of-limits condition (refer to Section II above) is to be brought at once to the attention of the manager of Static Testing for action. The completed forms will periodically be sent to the Program Manager for review and analysis.

2. Once each shift (three times per day) the items (except #1) shown on the Check List Form NS-1359 (Figure A-2) will be inspected and acknowledged (initialed). Any discrepancy will be brought promptly to the attention of the Manager of Static Testing.

3. At the start of the endurance test, then every 100 hours for the first 500 hours, and then each 500 hours, the supplemental test data information (use form shown in Figure A-3) including resistance of windings, resistance to ground, stator/duct cavity pressure, etc. will be obtained. The results will be referred to the Program Manager.

4. At the start of the endurance test, then after 500 hours, 1000 hours, and each subsequent 1000 hours or as directed by the Program Manager, a sample will be taken of the potassium and analyzed for O_2, C and Ta. The results will be referred to the Program Manager.

BOILER FEED EM PUMP PERFORMANCE DATA

Date	Hour	Test Run	Operator

Remarks ______________________________

____

FLOWS

K-flow ________ MV ________ lb/sec ________ gpm

K-Orifice Inlet ________ psig ΔP ________ psi

________ lb/sec ________ gpm

NaK Flow ________ MV ________ lb/sec ________ gpm

PRESSURES

Pump Suction ________ MV ________ psia

Pump Discharge (PK2) ________ MV ________ psia

(PK3) ________ MV ________ psia

Pump Cavity ________ MV ________ psia

Pump Head ________ psi

POWER

Electrical Input ________ KW

Voltage $\phi 1$ ________ $\phi 2$ ________ $\phi 3$ ________

Current L1 ________ L2 ________ L3 ________ amps

KVA ________ $\left(\frac{1.73 \times V_{AV} I_{AV}}{1000}\right)$

CALCULATIONS

Power Factor $\frac{\_\_\_\_\_\_ \text{ KW}}{\_\_\_\_\_\_ \text{ KVA}}$ = ________

Hydraulic Power = $\frac{0.195 \_\_\_\_\_\_ \text{ lb/sec } \_\_\_\_\_\_ \Delta P}{\_\_\_\_\_\_ \text{ Density, lb/ft}^3}$

= ________ KW

Efficiency = $\frac{\_\_\_\_\_\_ \text{ Hydraulic KW}}{\_\_\_\_\_\_ \text{ Elect. KW}}$

= ________ %

TEMPERATURES (^{o}F)

Ind.Pos.	Location	Reading	Corr.
1	K-Pump Suction		
2	K-Pump Suction		
3	K-Pump Discharge		
4	K-Pump Discharge		
5	NaK-Pump Inlet		
6	NaK-Pump Inlet		
7	NaK-Pump Outlet		
8	NaK-Pump Outlet		
9	Pump Winding (Term. End)		
10	Pump Winding (Term. End)		
11	Pump Winding		
12	Pump Winding		
13	Pump Rear Cavity (Stator)		
14	Pump Front Cavity (Duct)		
15	Power Feed Thru No. 1		
16	Power Feed Thru No. 2		
17	Power Feed Thru No. 3		
18	Leakage Probe		
19	K-Flow Meter		
20	NaK Flow Meter		
21	Press. Transd. (PK-1)		
22	Press. Transd. (PK-2)		
23	Press. Transd. (PK-3)		
24	K-Orifice		
25			
26			
27			
28			
29			
30			

NS 1304 (7-69)

Figure A-1

EM BOILER TEST FACILITY

CHECK LIST

The following checks shall be performed once per shift during performance testing and once per day on the 1st shift during endurance testing. The date, time and initials of the technician making the check shall be recorded on this sheet for each item.

Item	Date Time	Initials	Date Time	Initials	Date Time	Initials
1. Record complete set of data on NS 1304.						
2. Check chart paper, ink supply & standardize recorders & indicators.						
3. Test annunciation system (all lights on)						
4. Check Pyr-A-Larm Power light on.						
5. Check level probe power supplies & record current						
6. Check cell for smoke.						
7. Check scrubber blower on, water flow normal, no high pressure accross filter. Listen for unusual noise.						
8. Check oil level and condition in vacuum pump.						
9. Check ground detector reading.						
10. Check NaK pump stator temperature.						
11. Bleed cooler air filter.						
12. Check argon supply pressure.						

Remarks:

Figure A-2

NS 1359

EM BOILER FEED PUMP SUPPLEMENT TEST DATA

PART I

Date	Time	Operators Initials	After Test#	Winding Temperature Front	Winding Temperature Back	Winding Resistance T1-2	Winding Resistance T2-3	Winding Resistance T1-3

PART II

Date	Time	Resistance To Ground	Cavity Temperature Stator	Cavity Temperature Duct	Pressure Stator	Pressure Duct	Ground Detector Volts

Figure A-3

APPENDIX B

FINAL PUMP PERFORMANCE TEST PLAN

I. INTRODUCTION

The EM boiler feed pump has been on endurance test since August 18, 1969. It will have accumulated a total operating time, at design point conditions, of 10,000 hours on October 26, 1970.

At the conclusion of the 10,000 hour test, a series of performance tests will be made, using 60 Hz shop power (the present power supply) to recheck certain operating conditions for comparison with the original data. Following this test work, the power supply will be changed to that which will be a quasi-square wave source as provided by a typical DC to AC inverter. A series of additional performance tests will then be made to obtain data using the inverter.

Following the last test series, the liquid metal will be removed from the pump, the pump cut from the test loop, and prepared for storage.

This test plan will outline the test point conditions and overall procedures for completing the contract test work.

II. PERFORMANCE TEST WITH 60 Hz SHOP POWER

1. At the end of the 10,000 hour endurance test period, and prior to the performance testing, sample and analyze the potassium in the test loop. Also, shut off the test pump and determine the winding and ground resistance, and the argon pressure in the pump and stator cavities.

2. Conduct the series of performance tests (a minimum of 15 test conditions). For details of the test conditions, refer to data in Table B-1.

Preferably the test runs should be in the sequence indicated in the table. At the start of the shift of testing, set the "Winding Temperature" meter relay (M1) alarm point at 1250°F and trip-off at 1300°F. Also, set the "K Test Pump Over-Pressure" alarm (M7) at 350 psia. However, the test must not be left unattended when conditions are near these maximums, and all limits must be reduced to the endurance test conditions when performance data taking is not in progress (M1 at 1200/1250°F and M3 at 250/300 psia).

3. Each new set of test conditions are to be established, and then the pump is to operate for a minimum of 15 minutes without adjustment of basic parameters (pressure and voltage) before recording the test data (use Form NS-1304, Figure A-1).

4. After all data is available, it will be plotted in curve form, and approved by the Project Manager, before shutting down the pump. When approved, the test pump will be shut off, the air coolers shut off, the NaK left circulating, and trace heaters energized so as to maintain the filled K loop at or near a temperature of 800°F.

III. <u>SET UP FOR TEST WITH POWER INVERTER</u>

1. The inverter, which will have been checked at assembly with low power, will be set on the concrete floor near the southwest corner of the test loop enclosure. Power input to the inverter will be attached, and output to the pump will be connected at the capacitor bus (under the pump) after disconnecting the existing supply cables and all capacitors. Connect a cathode ray oscilloscope to the output transformers for checking purposes.

2. Proper control of the supply voltage will be checked after the wiring has been inspected, and before power is applied to the pump. This will be done with the disconnect under the pump in the open position. If

all checkouts are satisfactory, the pump disconnect may be closed, and performance testing, as described below, will be initiated.

IV. PERFORMANCE TEST WITH POWER INVERTER

1. This series of tests will be conducted to obtain test data for the test conditions shown in Table B-2. These tests will cover a minimum of 25 different test conditions.

2. Preferably the test runs will be made in the sequence indicated in the table. At the start of each shift of testing, set the "Winding Temperature" and "K Test Pump Over-Pressure" meter relays to the values given in II-2 above. At the close of the daily shift of testing, the meter relays are to be returned to the endurance test conditions, for pump operation with limited technician attention.

3. Establish the test condition (as shown in Table B-2) for each test, and observe the pump operation for a minimum of 15 minutes without appreciable adjustment, before recording the test data (use Form NS-1304, indicating Frequency data). Also, make photographic records of the current and voltage wave shapes (as measured at the output of the inverter) for the test conditions indicated in Table B-2.

V. POST TEST ACTIVITY

1. At the conclusion of the performance test with the inverter, and after data has been accepted by the Program Manager as complete and satisfactory, remove power from the pump and again check winding and ground resistance. Then reconnect the 60 Hz shop power, after removing all connections for the inverter test. The NaK will continue to be circulated during this period of activity.

2. Re-energize the pump with 60 Hz shop power, bring K in the pump loop to 1000°F, and turn on trace heaters. Then dump both the K and NaK and de-energize the NaK pump. Sample and analyze the NaK.

Establish and maintain a vacuum on both loops, and keep reduced power on the test pump to maintain the winding temperature T/C's at approximately 1000°F. The T/C at the duct outlet should read between 700 and 800°F. Also, watch the duct cavity pressure, which must stay below 23 psia. Adjust the pump input power as needed to maintain the temperature and pressure levels. Lower the temperatures of the dump tanks to about 170°F at this period of time. Continue in this overall condition for at least 48 hours, and until instructions to proceed are given by the Program Manager, based on advice by the Materials Analysis engineers that the K and NaK have been essentially all distilled from the pump duct and cooling passages.

3. Valve off the dump tanks, remove power from the pump, and let it cool to room temperature. Then remove all insulation, power leads, and T/C's, and prepare to cut the pump from the test loops. Make a final (room temperature) check of winding and ground resistances. Also duct and stator cavity gas pressures.

4. Flood system with argon gas, making sure it circulates through pump passages without any problems. Then cut all pipes with cover gas flowing, stopper the openings, and remove pump from test loop.

5. Seal all pipe openings and fill duct and stator cavity with pure argon at 15 psi pressure. Prepare, pack, and ship pump to NASA-Lewis, as instructed by Project Manager.

TABLE B-1

FINAL PUMP PERFORMANCE TEST CONDITIONS WITH 60 Hz SINE WAVE POWER

with: Potassium Inlet Temperature of 1000°F $\pm$ 10°F
NaK Inlet Temperature of 800°F $\pm$ 10°F and Δt = 50°F
Pump Inlet Pressure of 8.0 psia

Test No.	Pump Power, Volts	Potassium Flow Rate-lb/sec
FP1	135	3.25
FP2	↑	3.75
FP3	|	4.25 (or max possible)
FP4	↓	2.75
FP5	135	2.25 (or min for 350 psi)
FP6	85	4.0 (or max possible)
FP7	↑	3.25
FP8	|	2.5
FP9	↓	1.5
FP10	85	0.75
FP11	45	0.75
FP12	↑	1.2
FP13	|	1.6
FP14	↓	2.0
FP15	45	2.5 (or max possible)

TABLE B-2

PUMP PERFORMANCE TEST CONDITIONS USING INVERTER

with: Potassium Inlet Temperature of 1000°F ± 10°F
NaK Inlet Temperature of 800°F ± 10°F
Pump Inlet Pressure of 8.0 psia

Test No.	Pump Power Volts	Pump Power Frequency, Hz	Potassium Flow Rate lb/sec
* CP1	45	60	0.75
CP2			1.2
CP3			1.6
CP4			2.0
* CP5	45		2.5 (or max possible)
* CP6	85		4.0 (or max possible)
CP7			3.25
CP8			2.5
CP9			1.5
* CP10	85		0.75
* CP11	135		2.25 (or min. for 350 psi)
CP12			2.75
CP13			3.25
CP14			3.75
* CP15	135	60	4.25 (or max possible)
* CP16	45	45	0.75 (or min possible)
CP17			1.2
CP18			1.6
CP19			2.0
* CP20	45	45	2.5 (or max possible)
* CP21	45	25	0.75 (or min possible)
CP22			1.2
CP23			1.6
CP24			2.0
* CP25	45	25	2.5 (or max possible)

* Take photos of cathode ray oscillope current trace

APPENDIX C

WATER FLOW TEST ON AN ALUMINUM PUMP DUCT TEST MODEL

By James P. Couch
NASA-Lewis Research Center

Pressure drop tests were made on an aluminum model of the boiler feed EM pump duct using water as the working fluid. The aluminum duct, including the tangential inlet and center return outlet, was dimensionally the same as the T-111 EM pump duct. The test facility was designed to allow the duct to be tested with flow entering the tangential inlet or the center return outlet. Instrumentation included calibrated bourdon tube pressure gages, a turbine flowmeter, and a thermocouple to measure water temperature.

Figure C-1 shows a plot of the pressure drop data taken in both the normal flow direction (flow entering the tangential inlet) and the reverse (flow entering the center return outlet). A total of 20 runs were taken in the normal flow direction and 12 in the reverse.

The data fit parallel straight lines on a log-log plot each with slopes of about 1.9. The difference between the curves is about 28 percent.

Because of the difference in physical properties between room temperature water and 1000°F liquid potassium, the pressure drops measured in the water tests are about 1.85 times larger than pressure drops in potassium at corresponding flow rates.

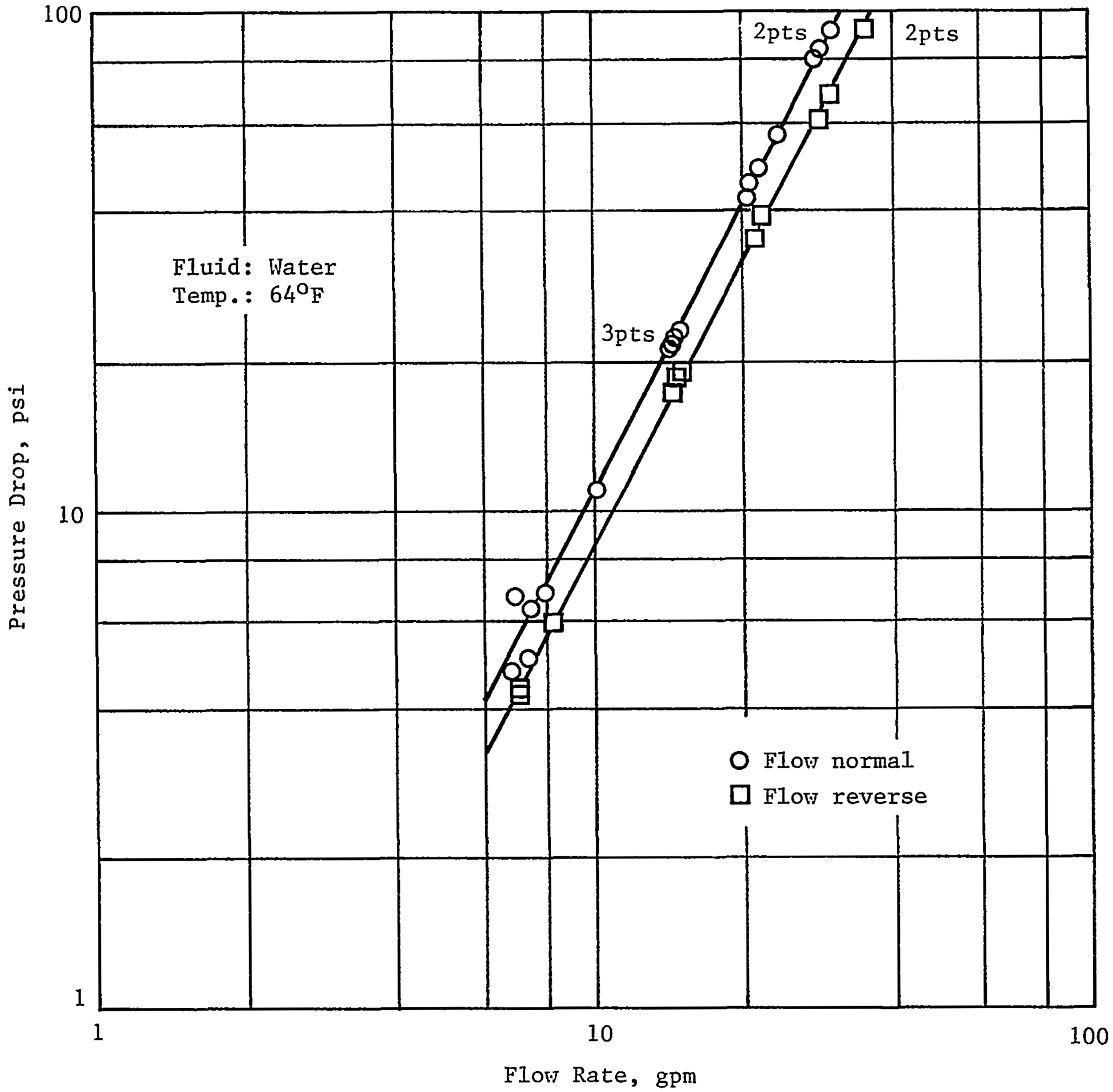

100
10
1
Pressure Drop, psi
1
10
100
Flow Rate, gpm
Fluid: Water
Temp.: 64°F
2pts
2pts
3pts
Flow normal
Flow reverse

Figure C-1

APPENDIX D

INVERTER CIRCUIT DESIGN AND OPERATION

By Robert J. Frye, Bill D. Ingle, and Martin E. Valgora
NASA-Lewis Research Center

The power source used for the quasi-square wave portion of the pump performance test program was a three-phase, silicon-controlled rectifier (SCR) static inverter. This inverter is capable of supplying more than 50 kVA. A schematic of the power output stage of this inverter is shown in Figure D-1. A unique feature of this type of inverter is that a common commutation circuit is shared by all the power thyristers, requiring only one commutating capacitor, C, and two inductors, L. The four commutating thyristers (SCR3 through SCR6) are alternately fired in pairs (SCR3 and SCR6 or SCR4 and SCR5), turning off all conducting load thyristers. This method of commutation requires that commutation occur at the zero crossing of each phase voltage or every 60 degrees. This will result in small notches in the output voltage waveforms at 60 degree intervals. The magnitude of the inverter output voltage may be varied by changing the D.C. input voltage to the inverter. The inverter was designed to operate at 25, 45 or 60 Hz.

Integrated circuitry was used to generate all the thyrister gate signals. A schematic of this circuitry and a timing diagram of some of the signals generated by this circuitry are shown in Figure D-2 and D-3. High threshold level (15 volt supply) digital logic was used because of its high noise margin and relatively slow switching speed. Both of these characteristics make this logic more immune to electrical noise.

The circuitry functions in the following manner. (Refer to Figure D-2) Operational amplifier IC1 is wired as an oscillator, producing a square-wave output three times the output frequency of the inverter. Three different operating frequencies may be obtained by means of the frequency-selector switch. A gate is connected to the output of the oscillator to improve the shape of the waveform and prevent loading the oscillator. The output of this gate is fed to the phase shift circuitry consisting of 12 gates (IC5, IC6 and IC7). In this portion of the circuitry the three phase signals and their complements are generated. The oscillator signal, phase A and its complement, is shown by Patterns 1, 2 and 3 of the timing diagram. (Figure D-3). Note that the phase shift output signal frequency is one-third that of the oscillator.

As previously mentioned, the commutation thyristers are alternately fired in pairs every 60 degrees, each pair being fired every 120 degrees of the output cycle. The necessary commutation pulses are generated by feeding the oscillator signal and its complement to a dual monostable multivibrator (IC3). The pulse width of the dual monostable is set for 20 μ sec. The two output signals of dual monostable (4 and 5, in the timing diagram) are buffered by the gates of IC13 and then fed to transistors Q1 through Q4 for current gain.

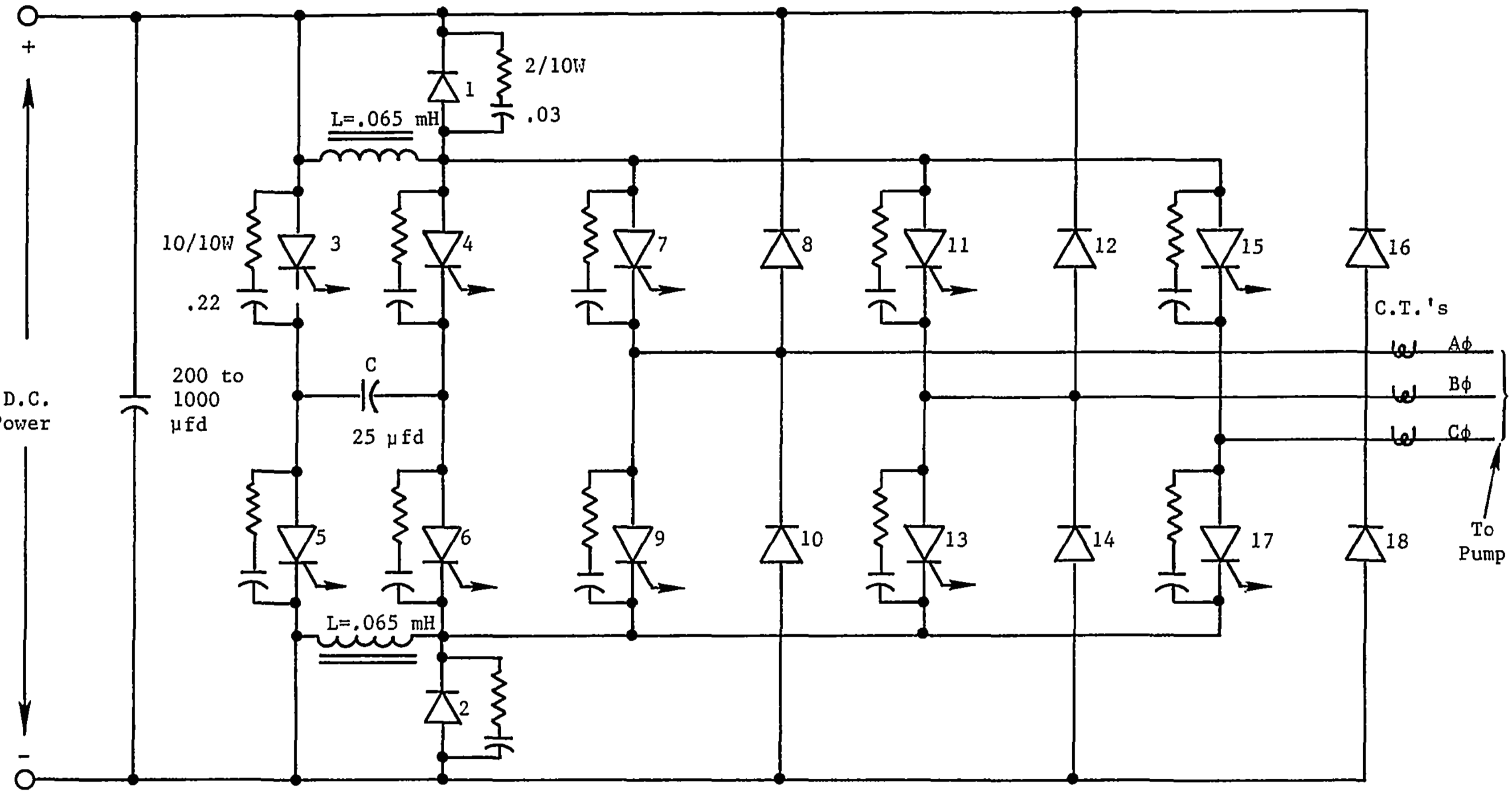
Each time commutation occurs, a time period or dwell time must be provided to ensure that commutation has been completed before the load thyristers are turned on. This is accomplished by taking the complement of both of the commutation pulse signals available at IC3 and gating them together. The output of the gate goes to monostable IC4. The monostable output signal (6 of the timing diagram) is combined with each of the phase-shift circuit outputs through the use of the six gates contained in

IC9, IC10 and IC11. Also fed to each of these gates is a continuous pulse train generated by the three gates of IC8 and the parts associated with them. The pulse train consists of 10 μ sec pulses every 100 μ sec. There are two advantages in using a pulse train to fire the load SCR's. If the initial pulse does not trigger the SCR, there are "backup" pulses available. Also, since the lagging power factor of the load (EM pump) will prevent the complement SCR of each phase from turning on until the reactive current flow is zero, the pulse train will permit the load SCR to be fired within 100 μ sec of the zero reactive current condition.

Connected to the same bus that supplies the pulse train is an "inhibit switch." When in the closed position, this switch grounds or inhibits each of the six gates (IC9-IC11) that supply firing pulses for the load SCR's. This mode of operation is used only during startup to ensure that commutation energy is available before firing pulses are sent to the load SCR's.

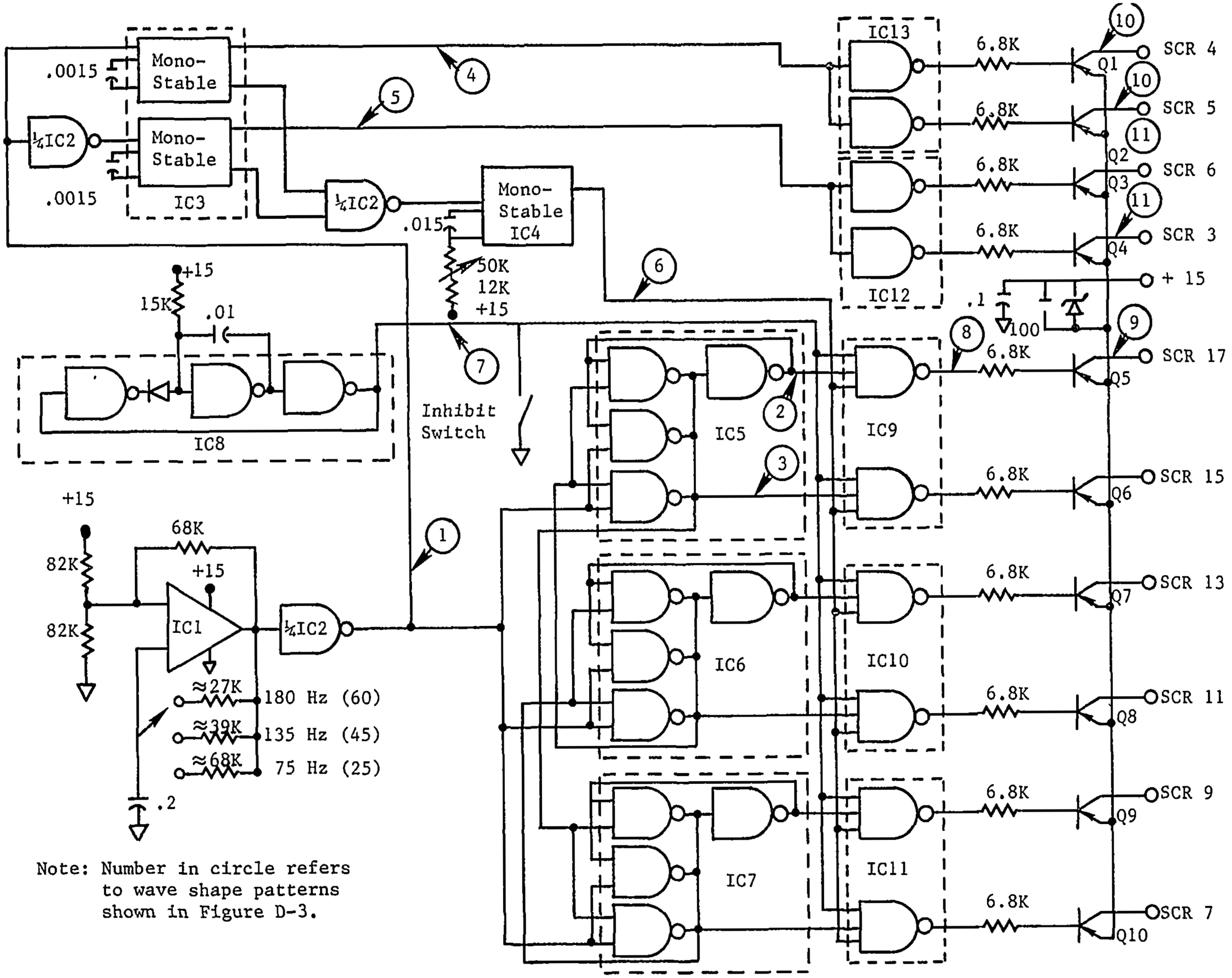
A typical output of one of the six gates (IC9-IC11) that combines the phase shift, dwell time and pulse train signals is shown by 8 on the timing diagram (Figure D-3). The outputs of these six gates are fed to transistors Q5 through Q10. These transistors invert the gate output signals and provide current gain. A typical output for one of these transistors is shown by 9 on the timing diagram.

The commutation and load SCR signals available at the output of transistors Q1 through Q10 are further amplified by ten identical drive circuits as shown in Figure D-4. The drive circuit primarily consists of a pair of transistors connected in a darlington configuration and driving a one-to-one pulse transformer. The output of the pulse transformer is diode coupled to the SCR, nominally supplying a 1.5A gate pulse.



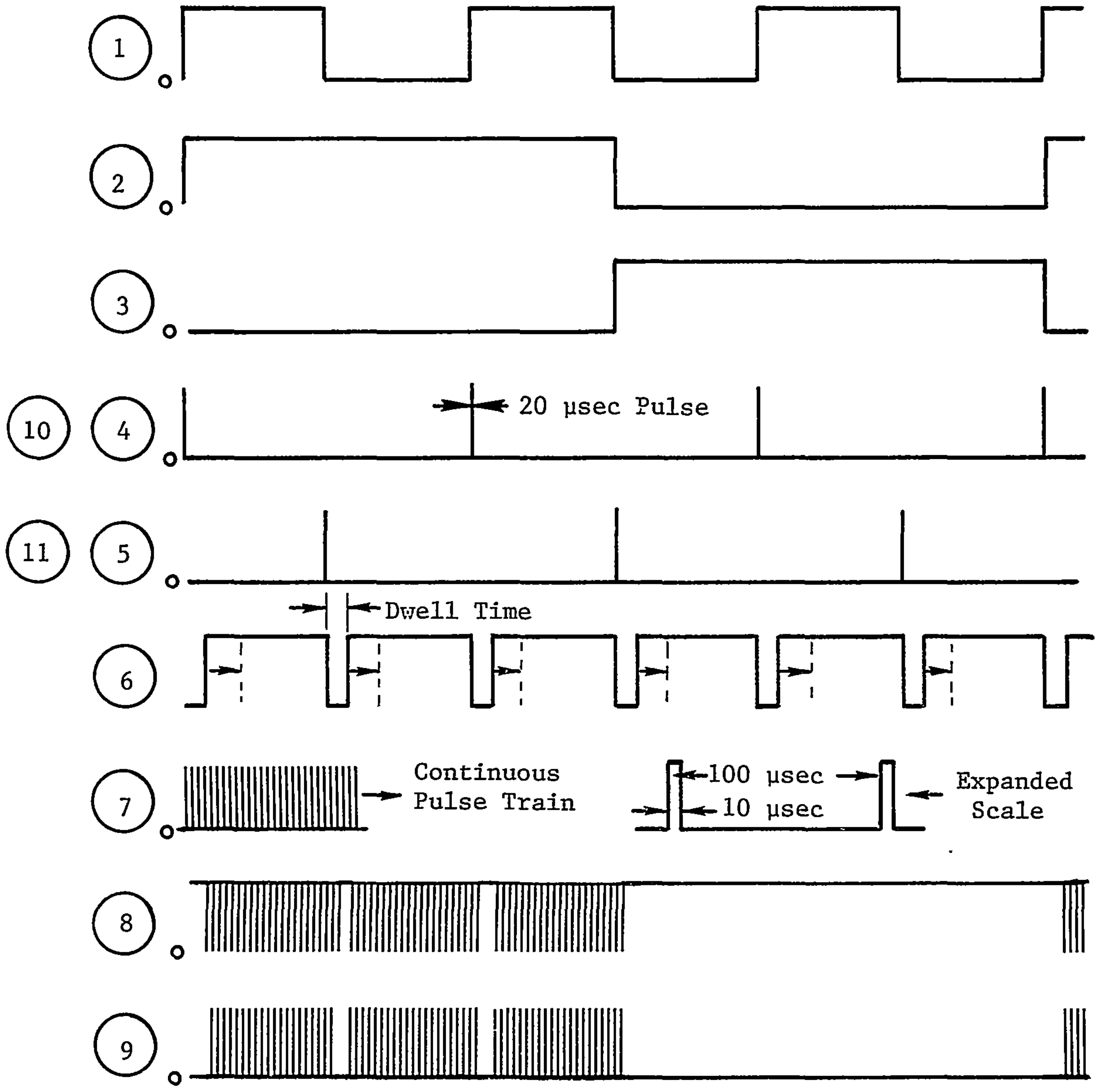
Note: All SCR's are GE #C185M
Diodes are #IN3742

Figure D-1. Three-Phase Power Inverter Schematic Diagram Main Power Components and Circuits.



Note: Number in circle refers to wave shape patterns shown in Figure D-3.

Figure D-2. Inverter Logic Circuitry.



Note: Refer to Figure D-2 for circuit locations of these wave patterns.

Figure D-3. Timing Diagram.

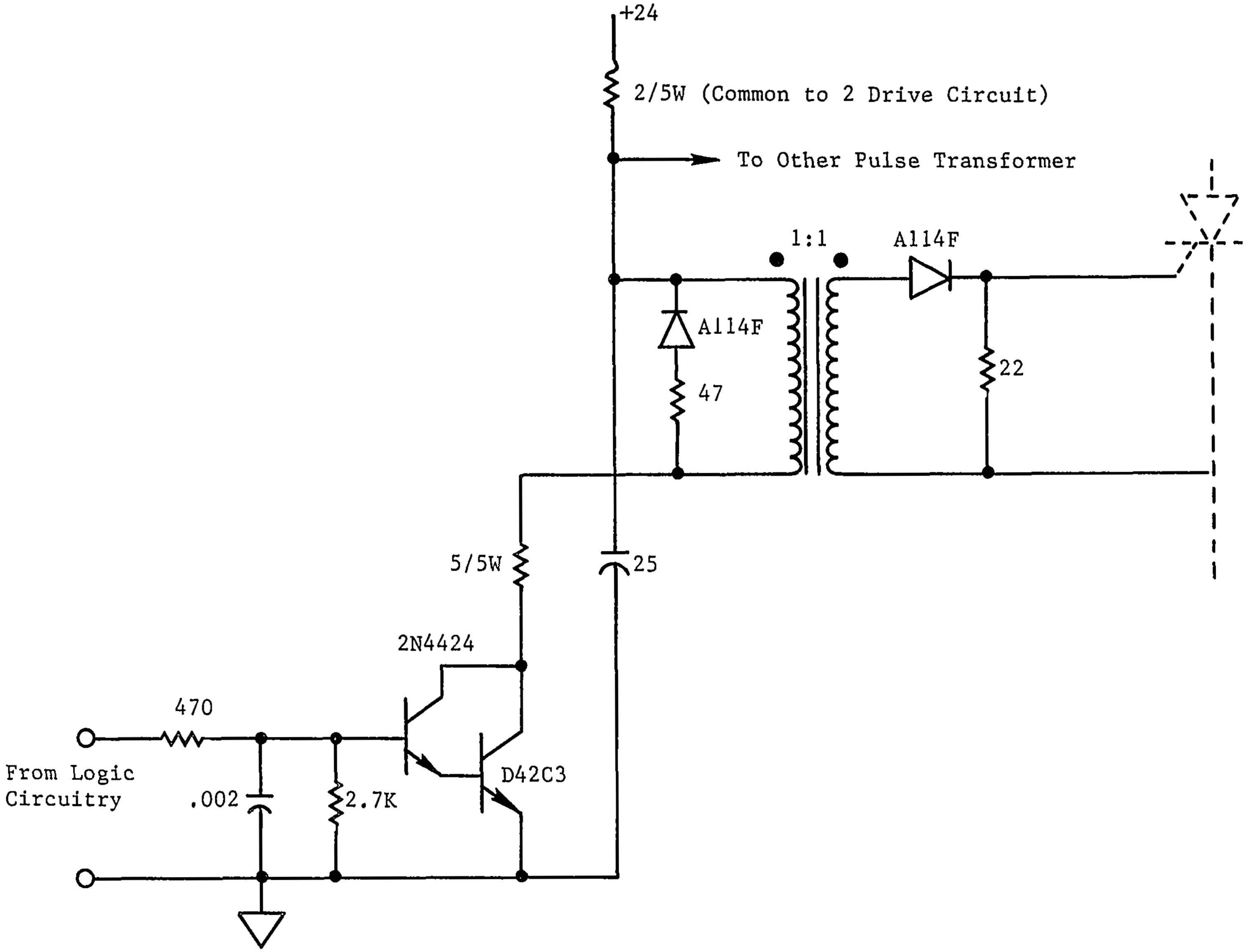
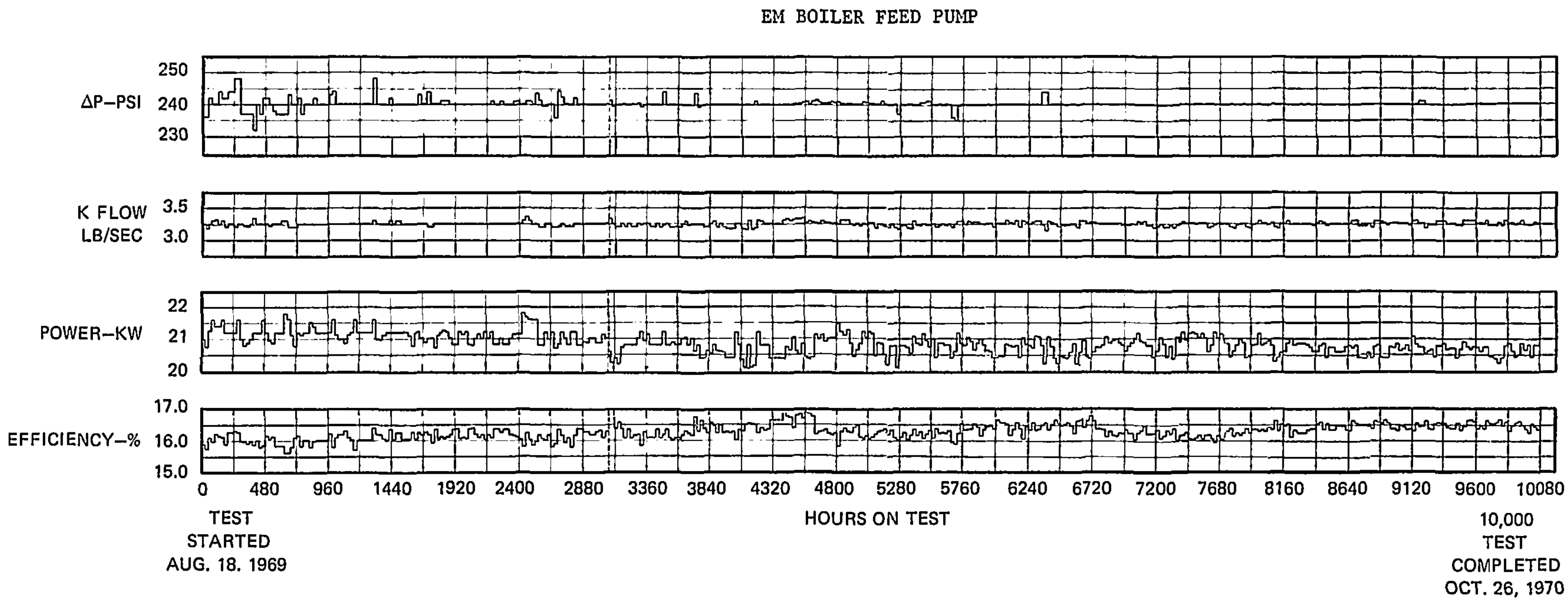


Figure D-4. Inverter Driver Stage.



Orig. AS-848 (Rev.)

Figure 1. Curves of Basic Data, Taken Daily During the Endurance Test.

BOILER FEED EM PUMP PERFORMANCE DATA

Date	Hour	Test Run	Operator
5-24-69	0725	E-15	JONES

Remarks VML-1 ½ [illegible] OPEN – GND Detector 0.4 Volts

FLOWS

K-flow 4.7 MV 3.3 lb/sec ______ gpm

K-Orifice Inlet – psig ΔP ______ psi

______ lb/sec ______ gpm

NaK Flow 4.15 MV .57 lb/sec 5.55 gpm

PRESSURES

Pump Suction 16.0 MV 8.0 psia

Pump Discharge (PK2) ______ MV ______ psia

(PK3) 38.25 MV 250 psia

Pump Cavity – MV 17.2 psia

Pump Head 242 psi

POWER

Electrical Input 21.6 KW

Voltage $\phi 1$ 133 $\phi 2$ 133 $\phi 3$ 133

Current L1 178.0 L2 177.9 L3 178.0 amps

KVA 40.92 $\left(\frac{1.73 \times V_{AV} I_{AV}}{1000}\right)$

CALCULATIONS

Power Factor $\frac{21.6 \text{ KW}}{40.92 \text{ KVA}} = .528$

Hydraulic Power $= \frac{0.195 \; 3.3 \text{ lb/sec} \; 242 \; \Delta P}{44.71 \text{ Density, lb/ft}^3}$

$= 3.48$ KW

Efficiency $= \frac{3.48 \text{ Hydraulic KW}}{21.6 \text{ Elect. KW}}$

$= 16.11$ %

TEMPERATURES ($^{\circ}$F)

Ind.Pos.	Location	Reading	Corr.
1	K-Pump Suction	1000	
2	K-Pump Suction	1000	
3	K-Pump Discharge	1017	
4	K-Pump Discharge	1018	
5	NaK-Pump Inlet	796	
6	NaK-Pump Inlet	796	
7	NaK-Pump Outlet	846	
8	NaK-Pump Outlet	846	
9	Pump Winding	1036	
10	Pump Winding	1040	
11	Pump Winding	1004	
12	Pump Winding	1025	
13	Pump Rear Cavity (Stator)	901	
14	Pump Front Cavity (Core)	930	
15	Power Feed Thru No. 1	484	
16	Power Feed Thru No. 2	457	
17	Power Feed Thru No. 3	504	
18	Leakage Probe	154	
19	K-Flow Meter	949	
20	NaK Flow Meter	729	
21	Press. Transd. (PK-1)	336	
22	Press. Transd. (PK-2)	481	
23	Press. Transd. (PK-3)	461	
24	K-Orifice	1021	
25			
26			
27			
28			
29			
30			

[illegible] (7-69) Figure 2. Copy of Actual Test Data Sheet for Results After 240 Hours on Test.

BOILER FEED EM PUMP PERFORMANCE DATA

Date	Hour	Test Run	Operator
10-7-70	1550	E-408	T. JONES

Remarks VML-1 3/4 TURN OPEN

FLOWS

K-flow 4.60 MV 3.25 lb/sec ____ gpm

K-Orifice Inlet ____ psig ΔP ____ psi

____ lb/sec ____ gpm

NaK Flow 4.0 MV .572 lb/sec 5.35 gpm

PRESSURES

Pump Suction 14.0 MV ____ psia

Pump Discharge (PK2) — MV — psia

(PK3) 38.0 MV 248.1 psia

Pump Cavity — MV 21.1 psia

Pump Head 240.0 psi

POWER

Electrical Input (.518 X 40) 20.72 KW

Voltage $\phi 1$ 130.0 $\phi 2$ 129.5 $\phi 3$ 131.0

Current L1 173.2 L2 170.8 L3 172.8 amps

KVA 38.81 $\left(\frac{1.73 \times V_{AV} I_{AV}}{1000}\right)$

CALCULATIONS

Power Factor $\frac{20.72 \text{ KW}}{38.81 \text{ KVA}} = .534$

Hydraulic Power = $\frac{0.195 \; 3.25 \text{ lb/sec} \; 240.0 \; \Delta P}{44.79 \text{ Density, lb/ft}^3}$

= 3.396 KW

Efficiency = $\frac{3.396 \text{ Hydraulic KW}}{20.72 \text{ Elect. KW}}$

= 16.39 %

TEMPERATURES (°F)

Ind.Pos.	Location	Reading	Corr.
1	K-Pump Suction	1000	
2	K-Pump Suction	1000	
3	K-Pump Discharge	1018	
4	K-Pump Discharge	1018	
5	NaK-Pump Inlet	797	
6	NaK-Pump Inlet	797	
7	NaK-Pump Outlet	844	
8	NaK-Pump Outlet	844	
9	Pump Winding	1026	
10	Pump Winding	1028	
11	Pump Winding	991	
12	Pump Winding	1040	
13	Pump Rear Cavity (Stator)	890	
14	Pump Front Cavity (Core)	929	
15	Power Feed Thru No. 1	481	
16	Power Feed Thru No. 2	463	
17	Power Feed Thru No. 3	497	
18	Leakage Probe	188	
19	K-Flow Meter	955	
20	NaK Flow Meter	726	
21	Press. Transd. (PK-1)	345	
22	Press. Transd. (PK-2)	352	
23	Press. Transd. (PK-3)	564	
24	K-Orifice	1030	
25			
26			
27			
28			
29			
30			

NS 1304 (7-69) Figure 3. Copy of Actual Test Data Sheet for Results After 9544 Hours on Test.

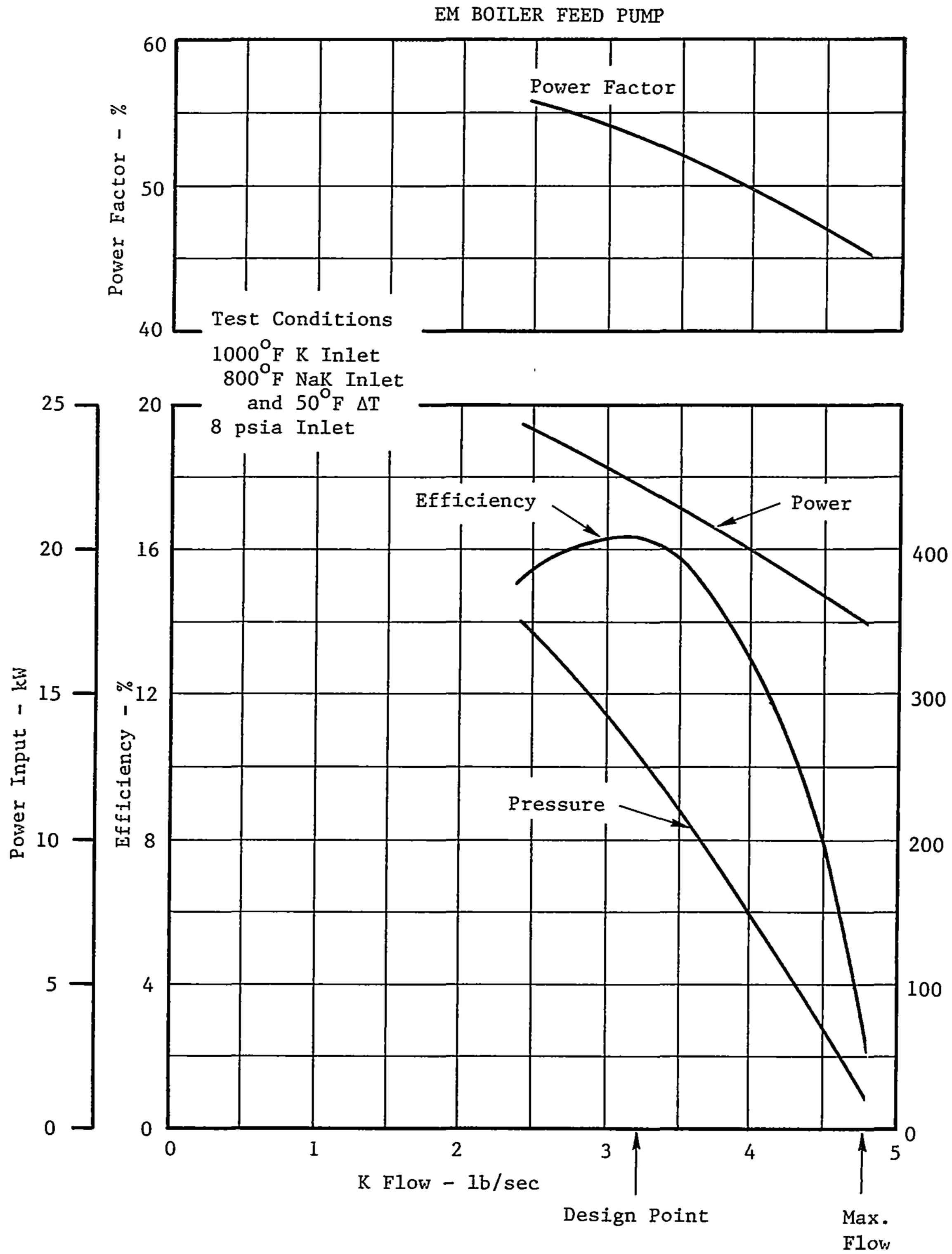


Figure 4. Final Performance Test Results (Curves) for 135 V, 60 Hz, Sine Wave Input Power.

EM BOILER FEED PUMP

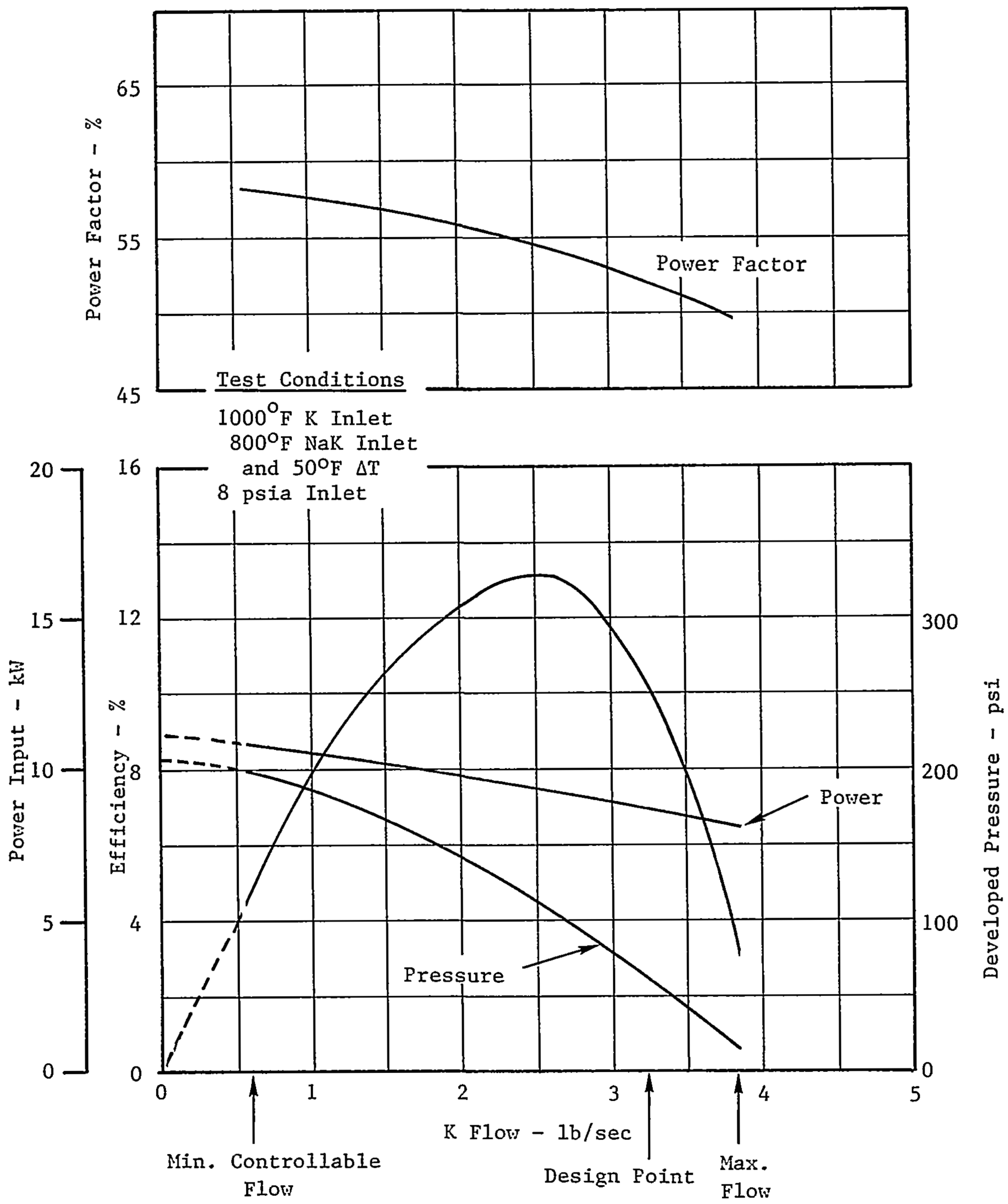


Figure 5. Final Performance Test Results (Curves) for 85 V, 60 Hz, Sine Wave Input Power.

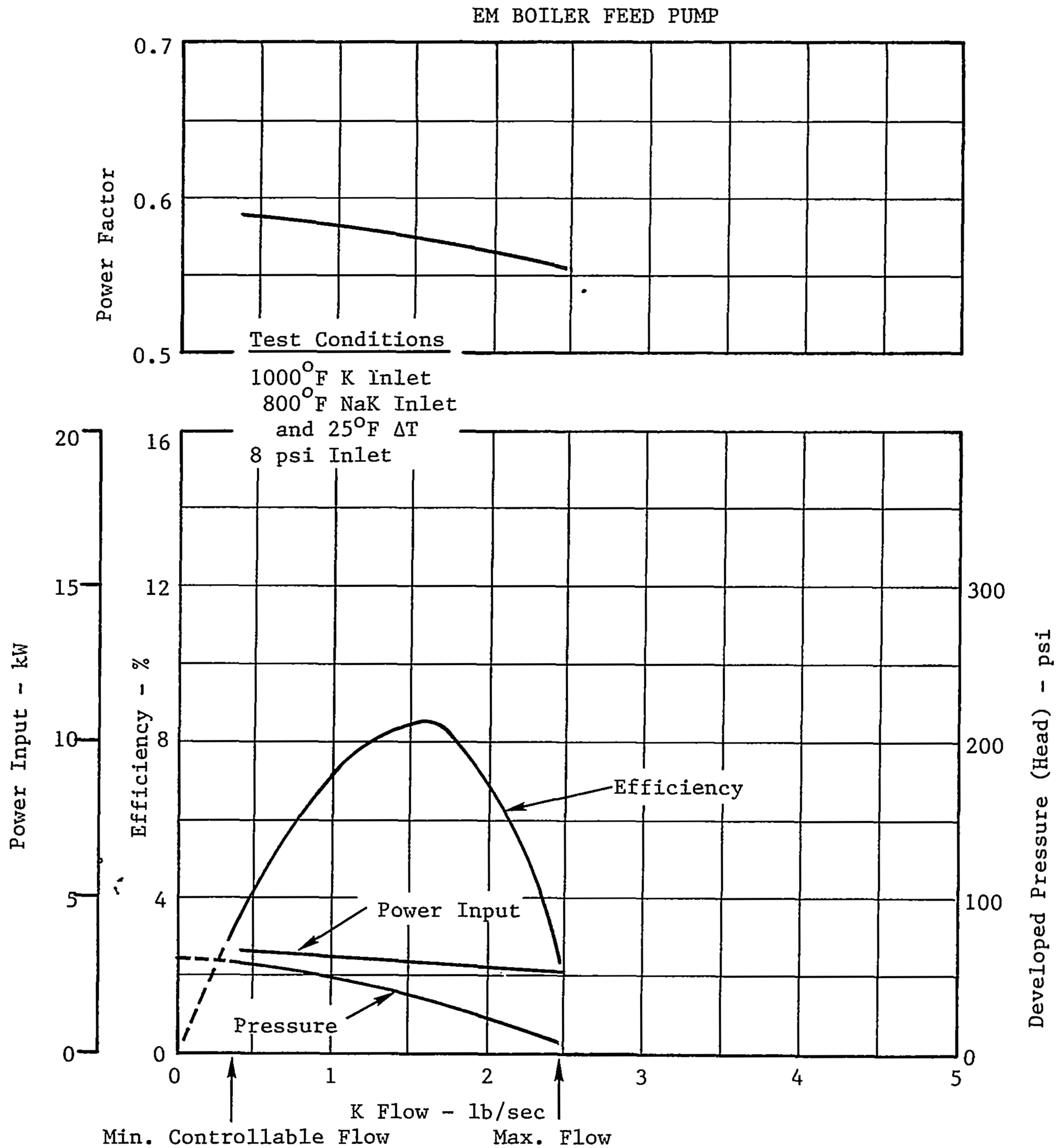


Figure 6. Final Performance Test Results (Curves) for 45 V, 60 Hz, Sine Wave Input Power.

EM BOILER FEED PUMP

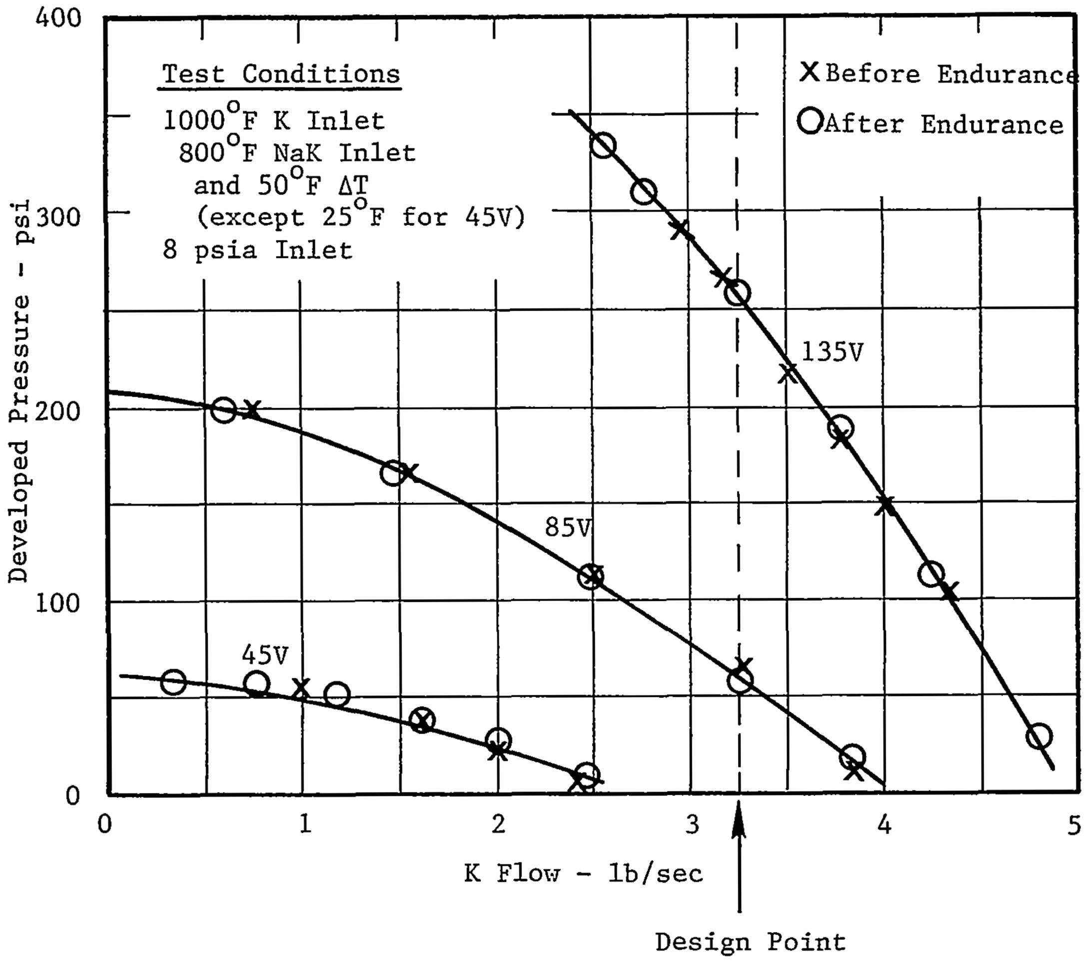


Figure 7. Performance Test Results Comparing Pressure Developed for Various Flows, at 45, 85, and 135 Volts, 60 Hz, Sine Wave Power.

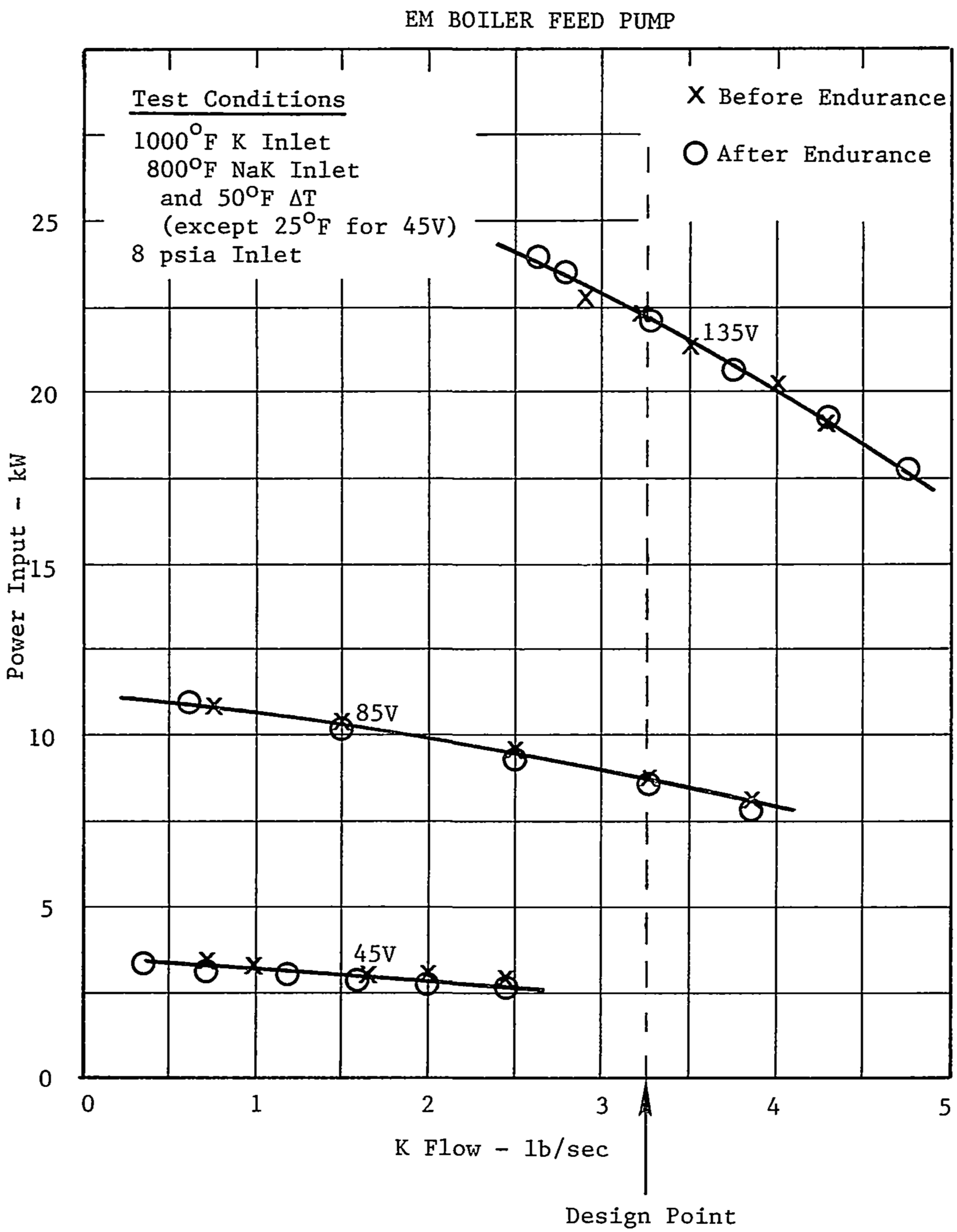


Figure 8. Performance Test REsults Comparing Power Input for Various Flow, at 45, 85, and 135 Volts, 60 Hz, Sine Wave Power.

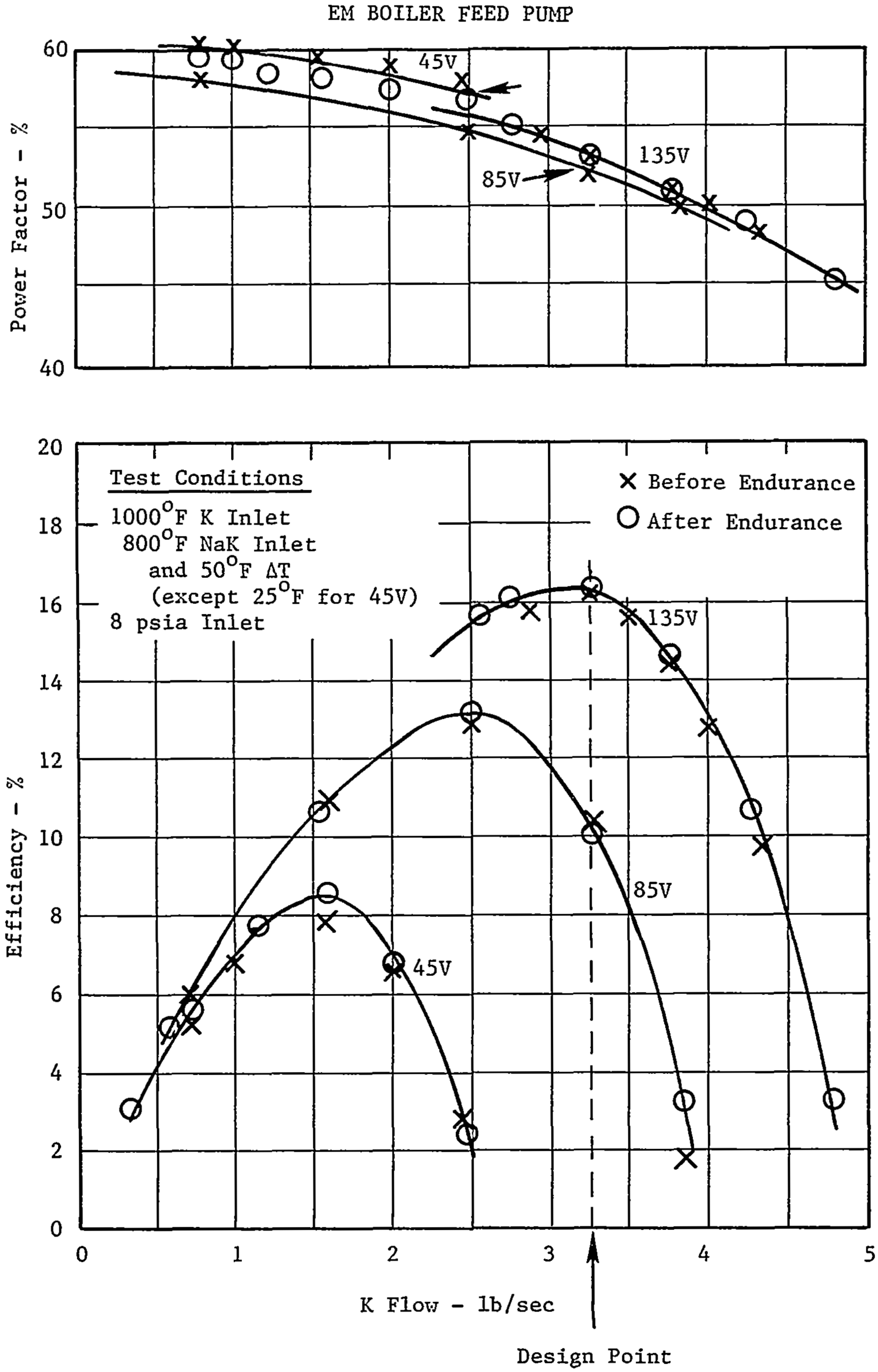


Figure 9. Performance Test Results Comparing Efficiency and Power Factor for Various Flows, at 45, 85, and 135 Volts, 60 Hz, Sine Wave Power.

EM BOILER FEED PUMP

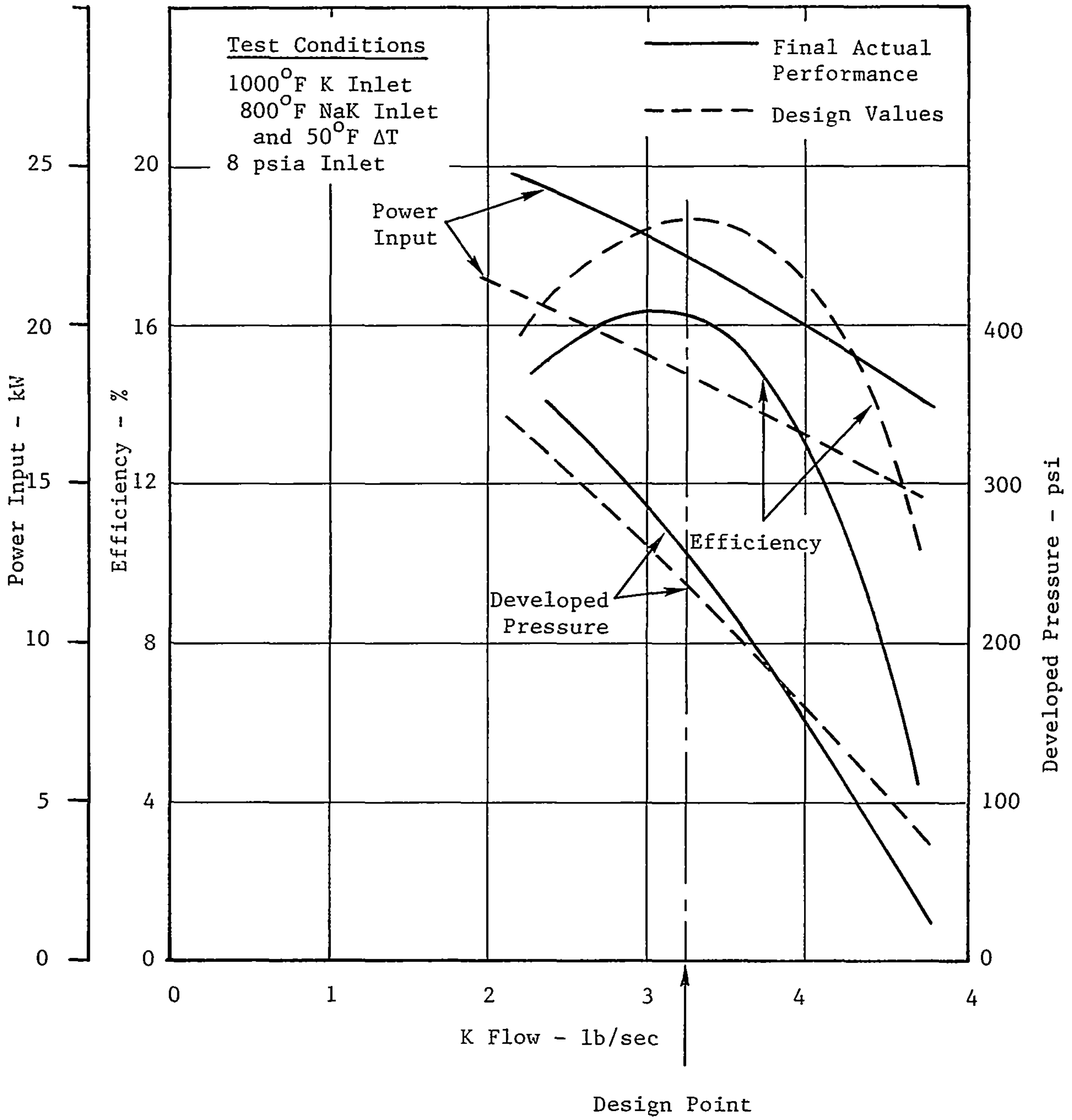


Figure 10. Final Performance Test Results (Curves) at 135 Volts, Compared with Original Design Predictions.

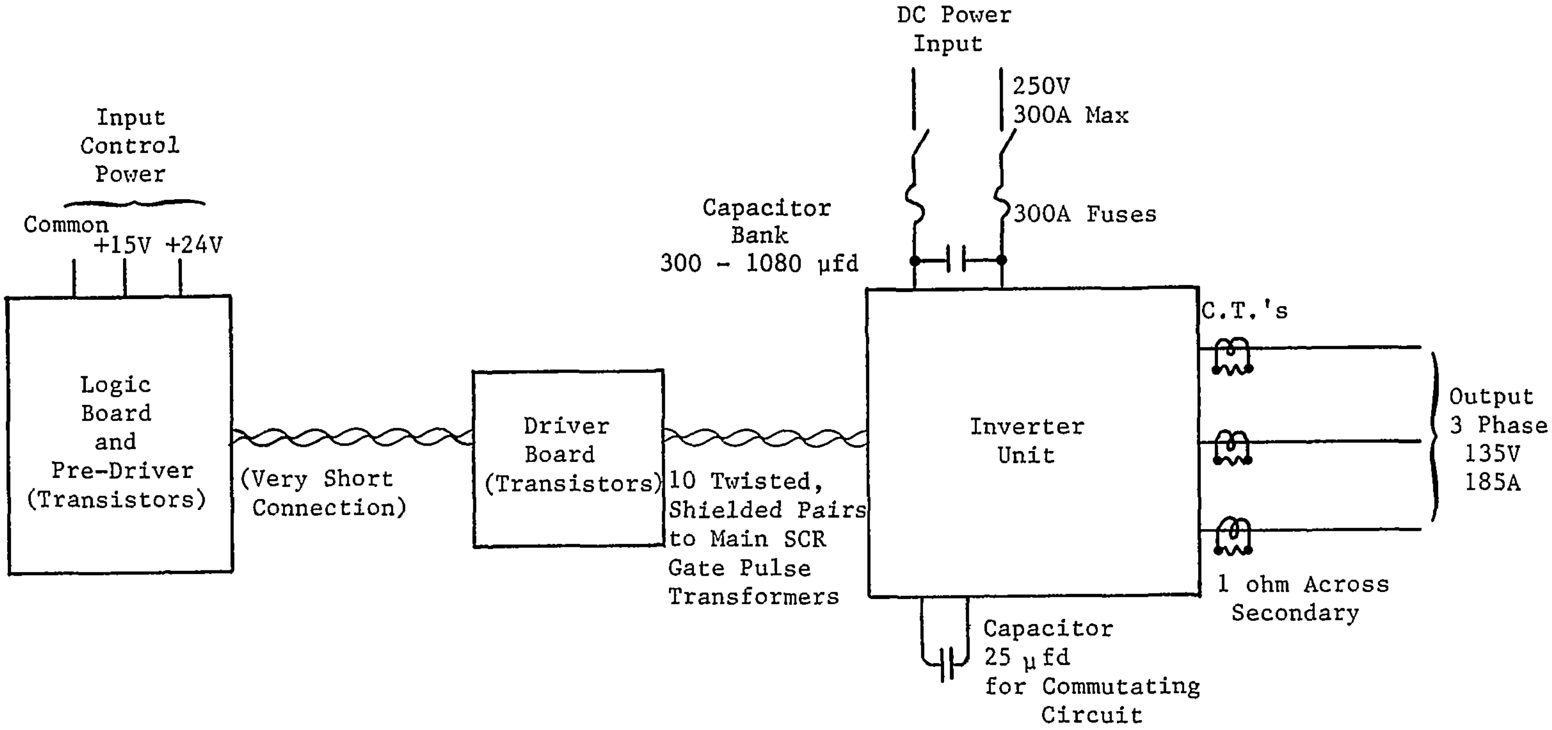


Figure 11. Block Diagram of Power Inverter Set-Up.

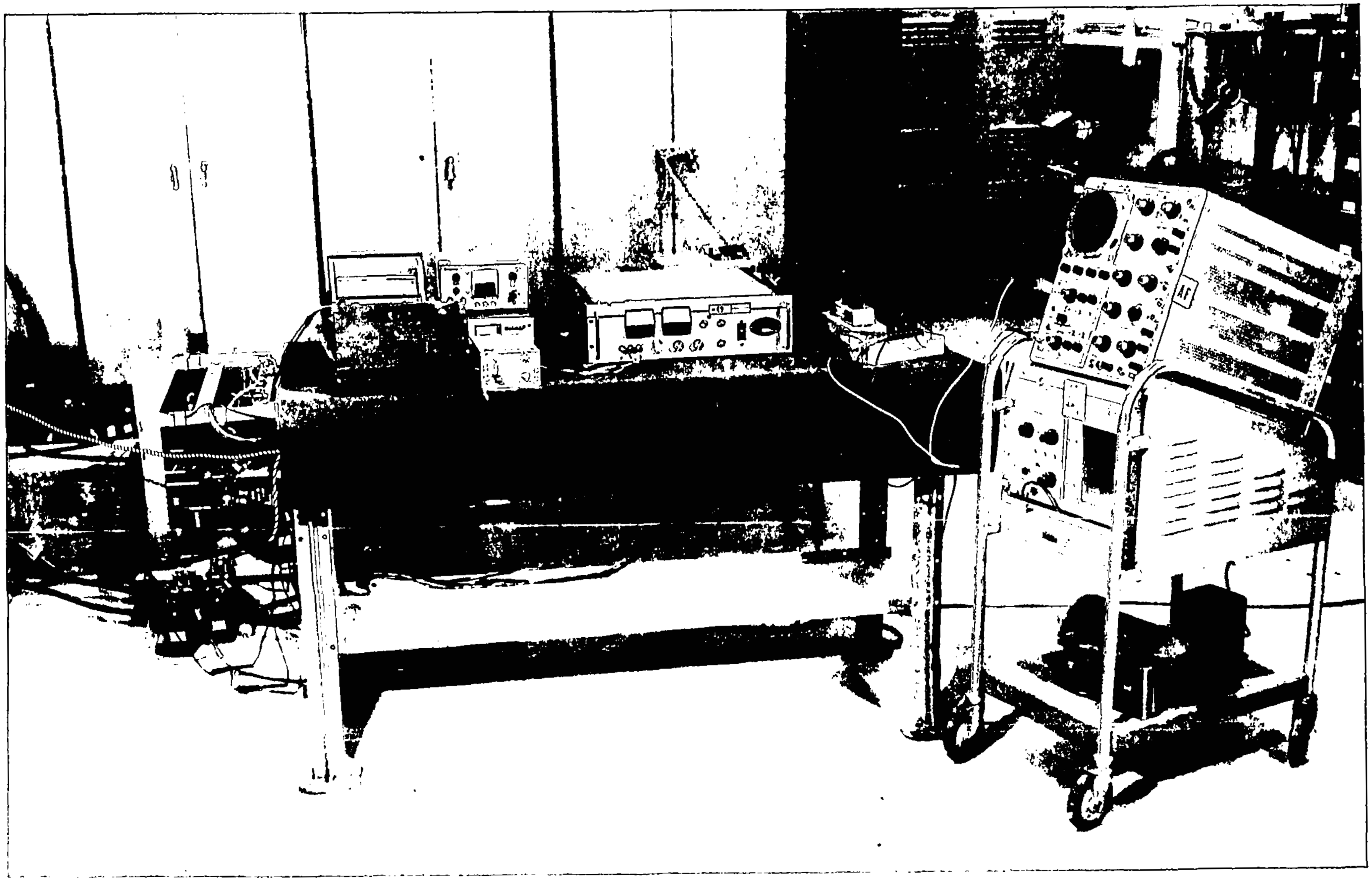


Figure 12. Overall View of Power Inverter Set Up Outside of Pump Test Cell.

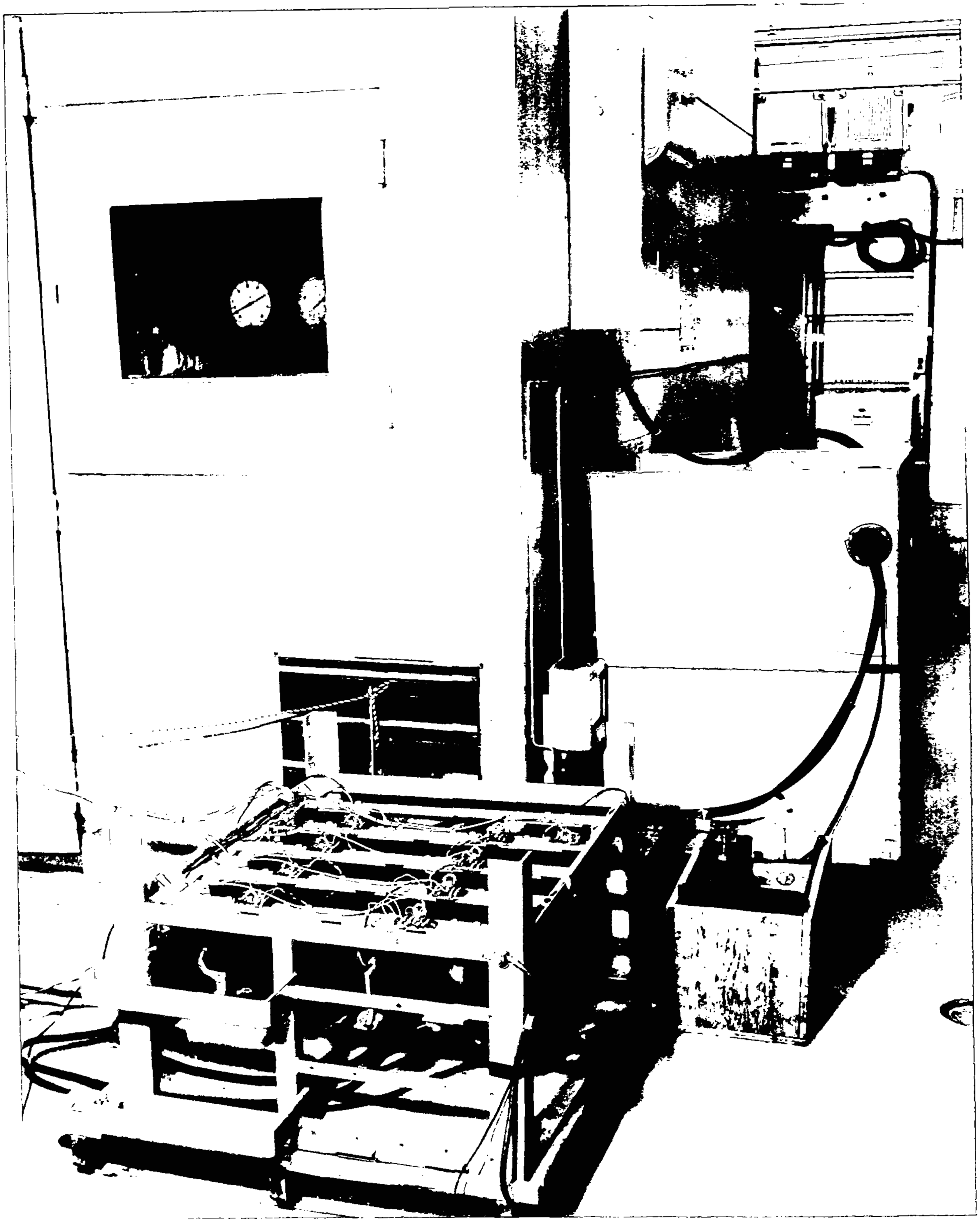


Figure 13. Close-Up of Power Inverter, Set Up Outside of Test Cell, Showing D.C. Input Leads and Capacitors

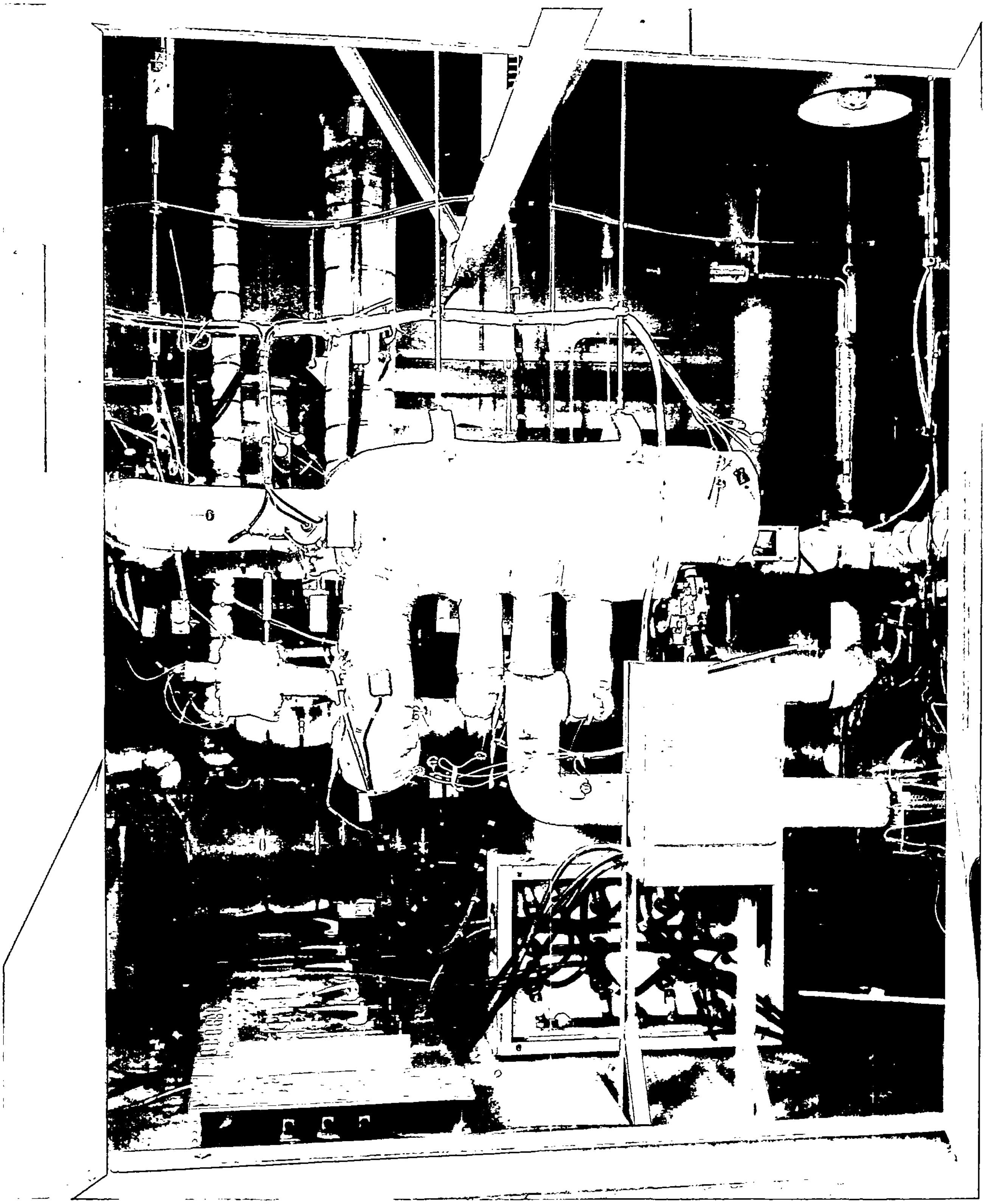


Figure 14. EM Pump in Test Loop with Selector Switches and Connections for Quasi-Square Wave Tests.

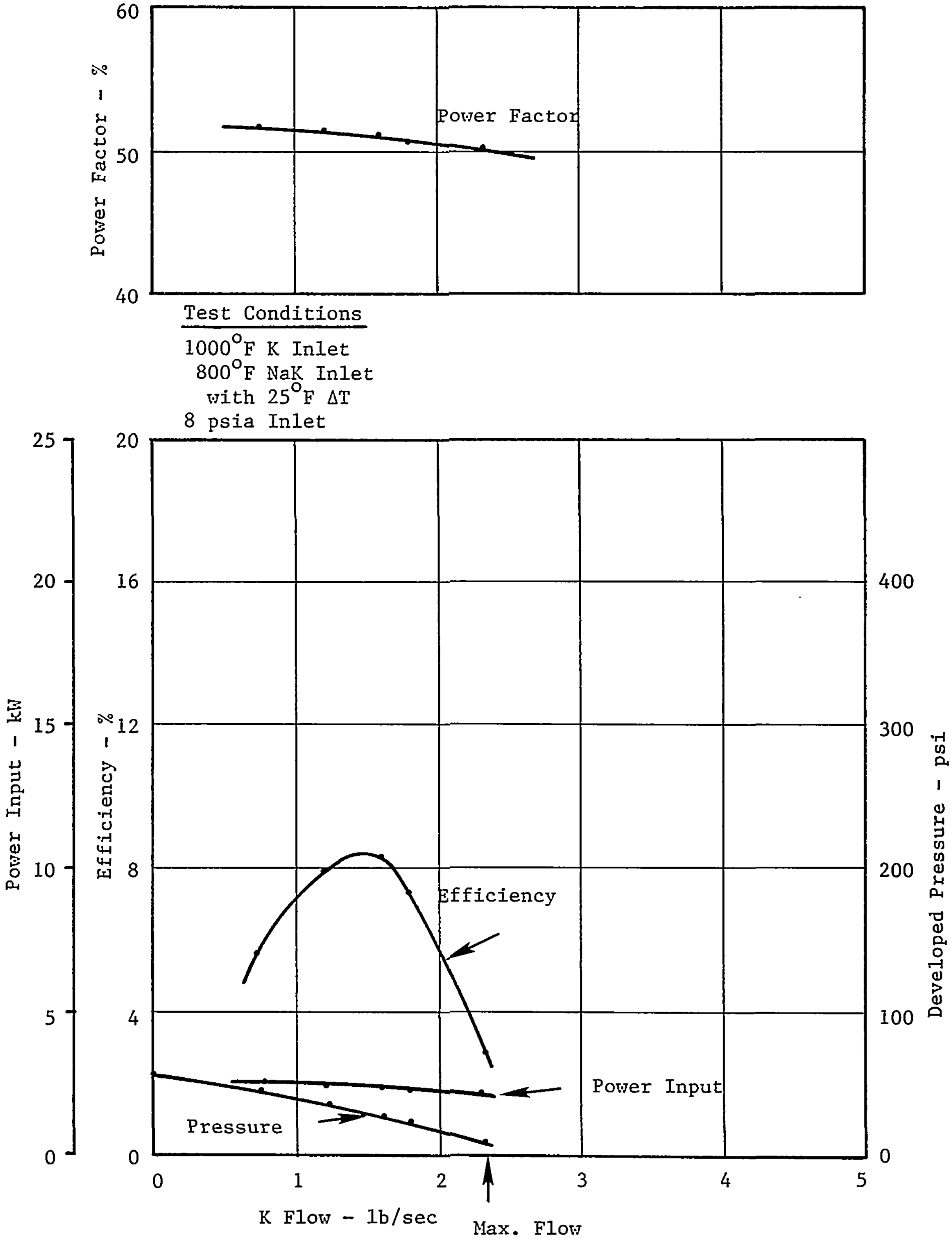


Figure 15. Performance Test Results for Input of 45 Volts, 60 Hz, with Quasi-Square Wave Power.

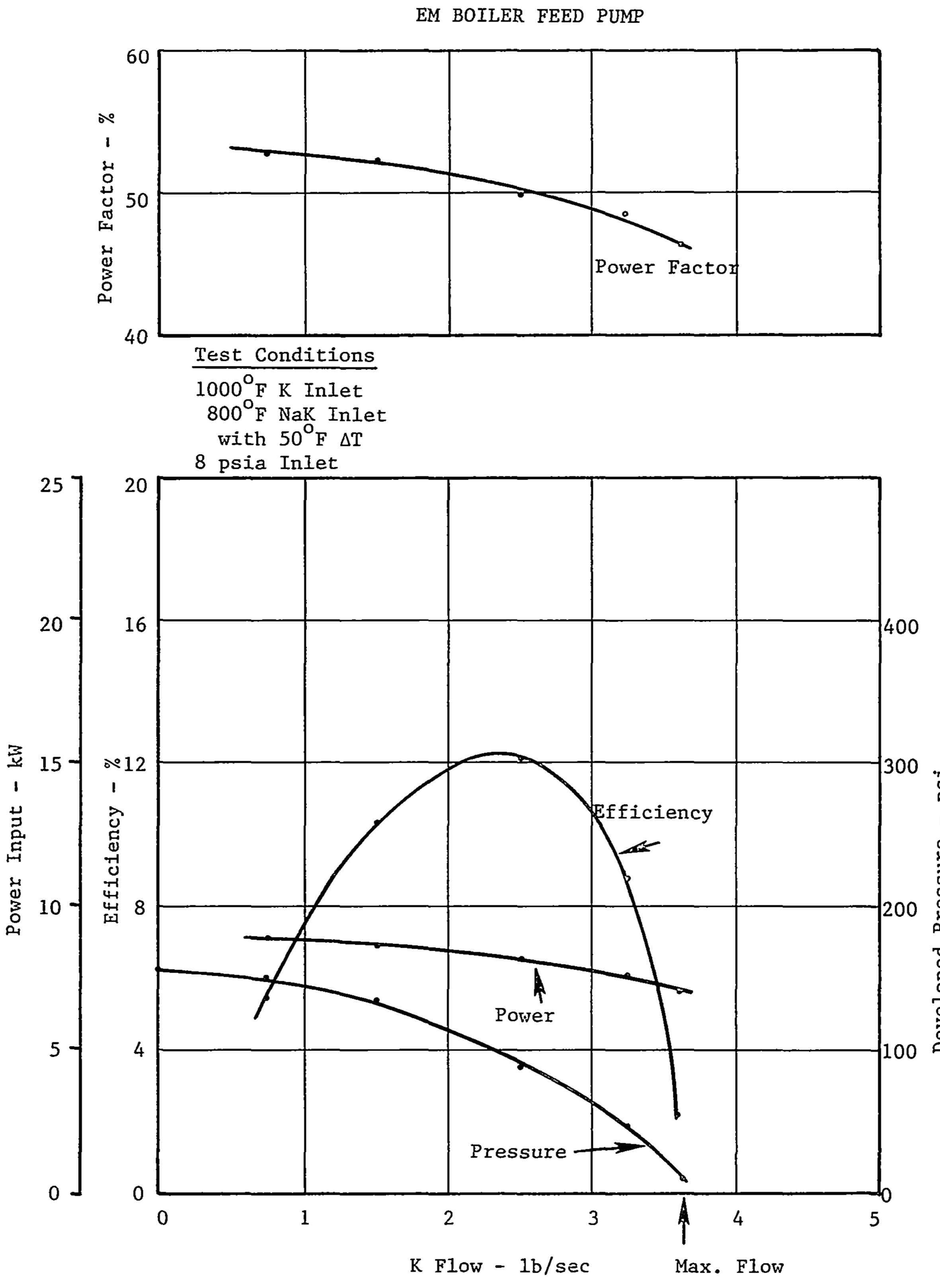


Figure 16. Performance Test Results for Input of 85 Volts, 60 Hz, with Quasi-Square Wave Power.

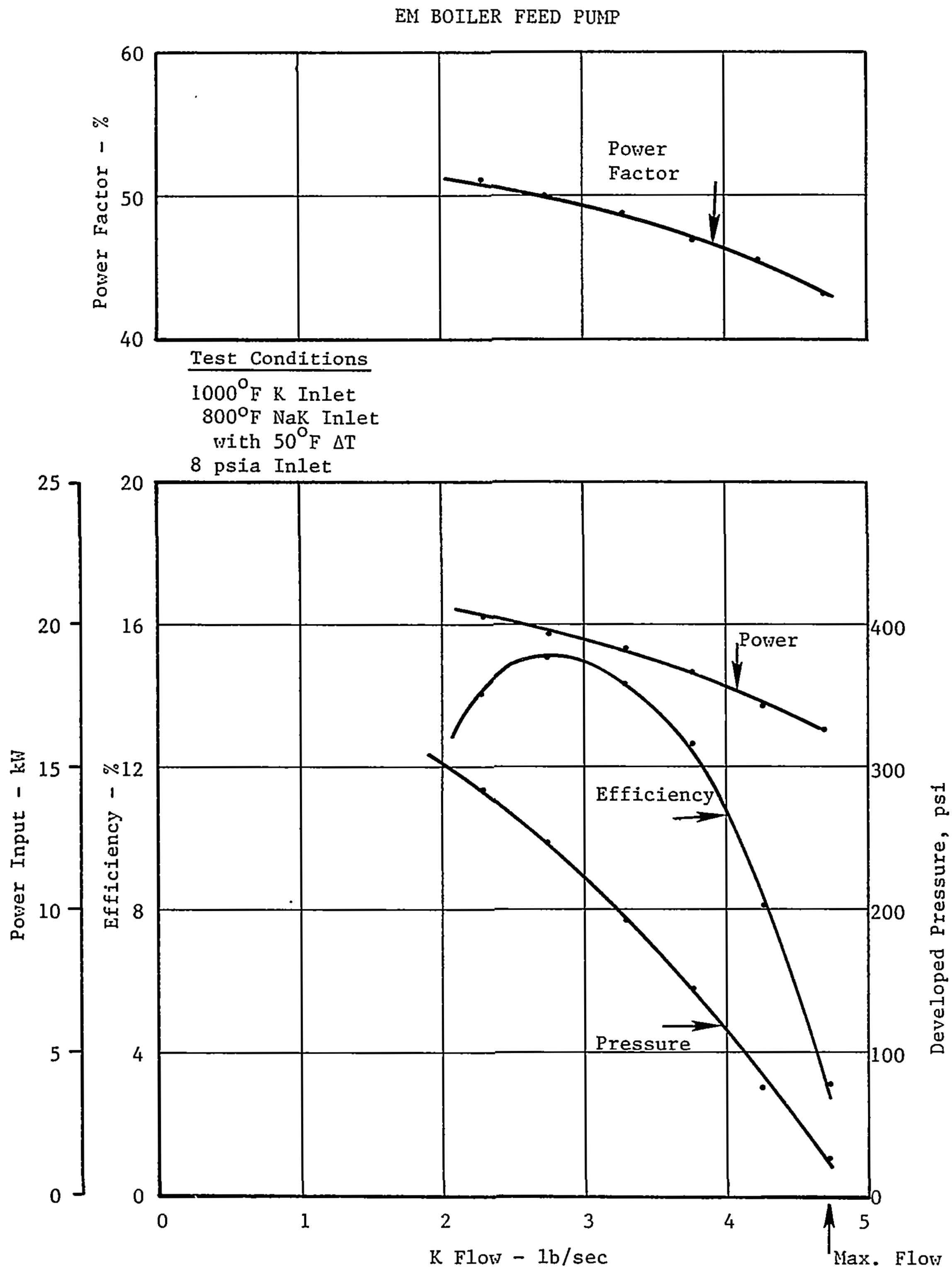


Figure 17. Performance Test Results for Input of 135 Volts, 60 Hz, with Quasi-Square Wave Power.

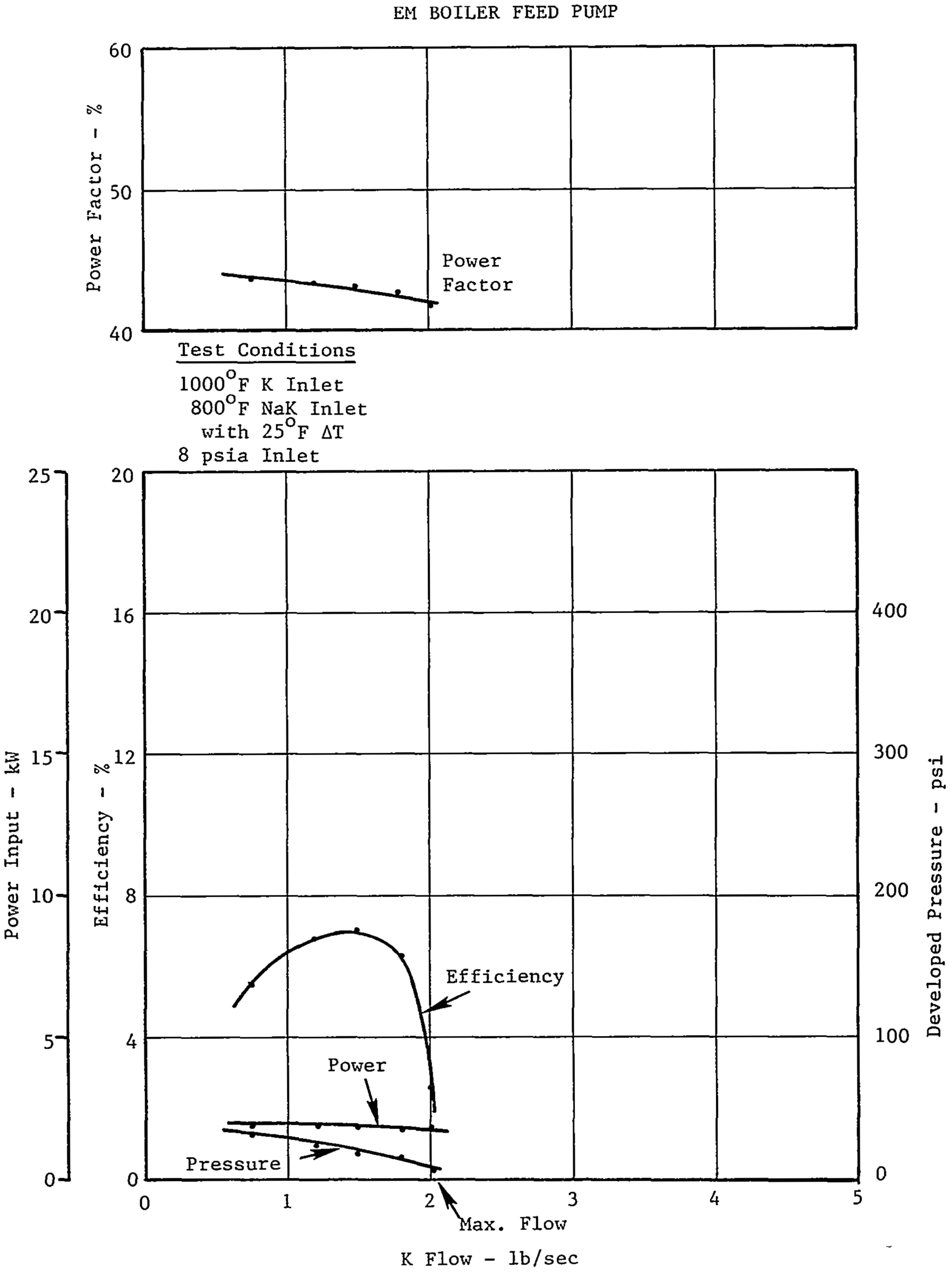


Figure 18. Performance Test Results for Input of 45 Volts, 45 Hz, with Quasi-Square Wave Power.

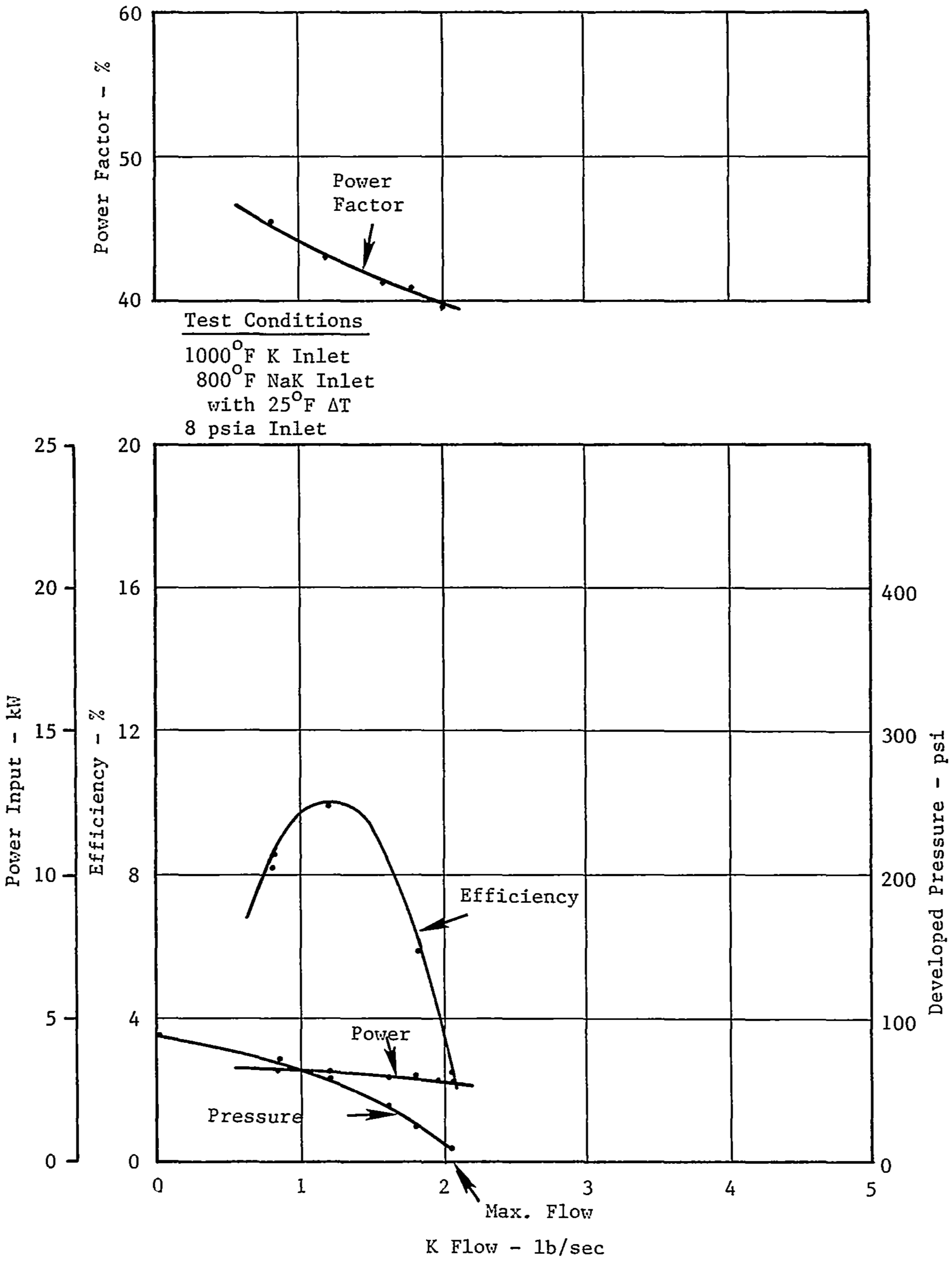


Figure 19. Performance Test Results for Input of 45 Volts, 25 Hz, with Quasi-Square Wave Power.

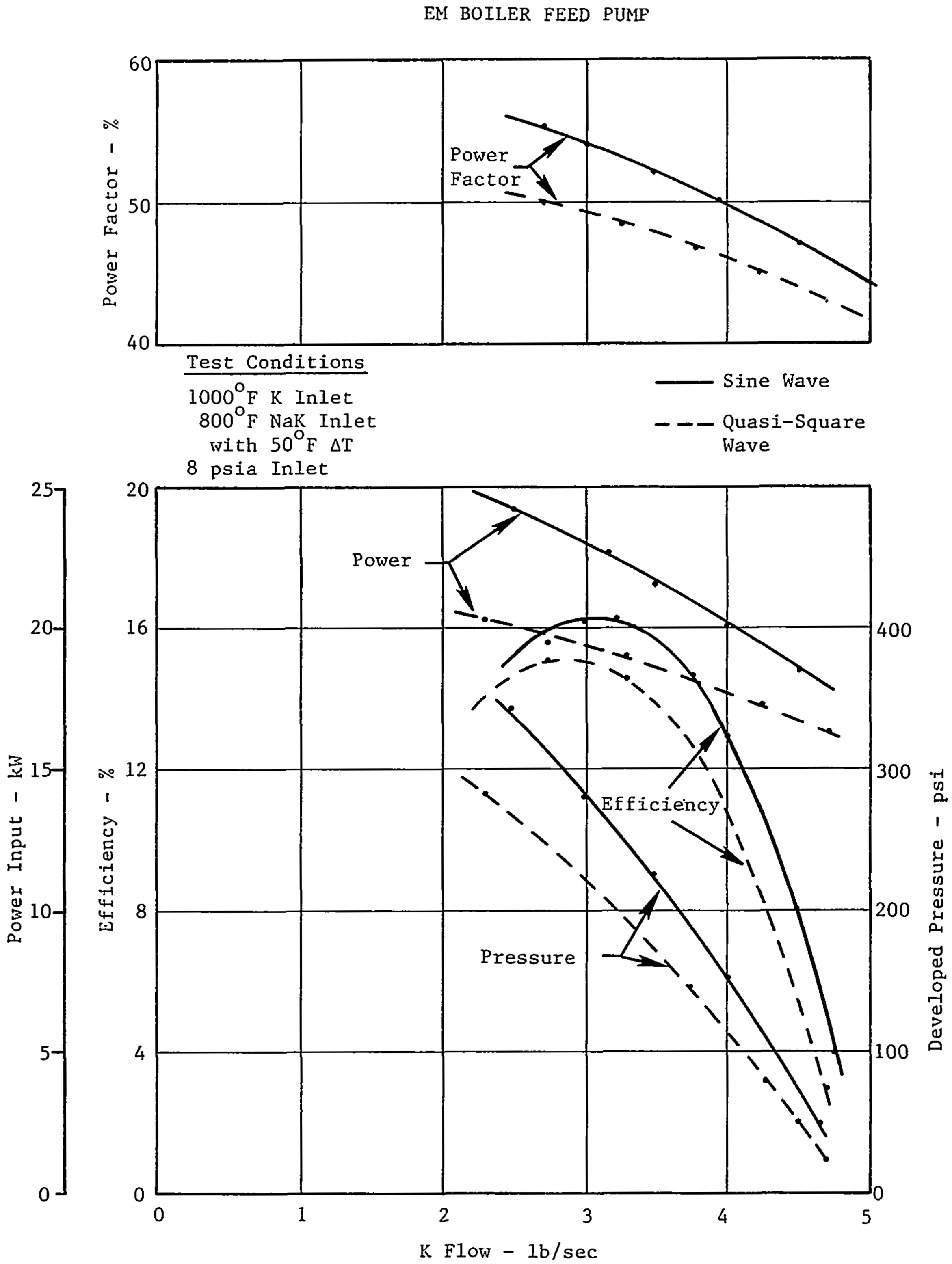


Figure 20. Comparison of Performance Results for Tests at 135 Volts, 60 Hz, with Sine and Quasi-Square Wave Input Power.

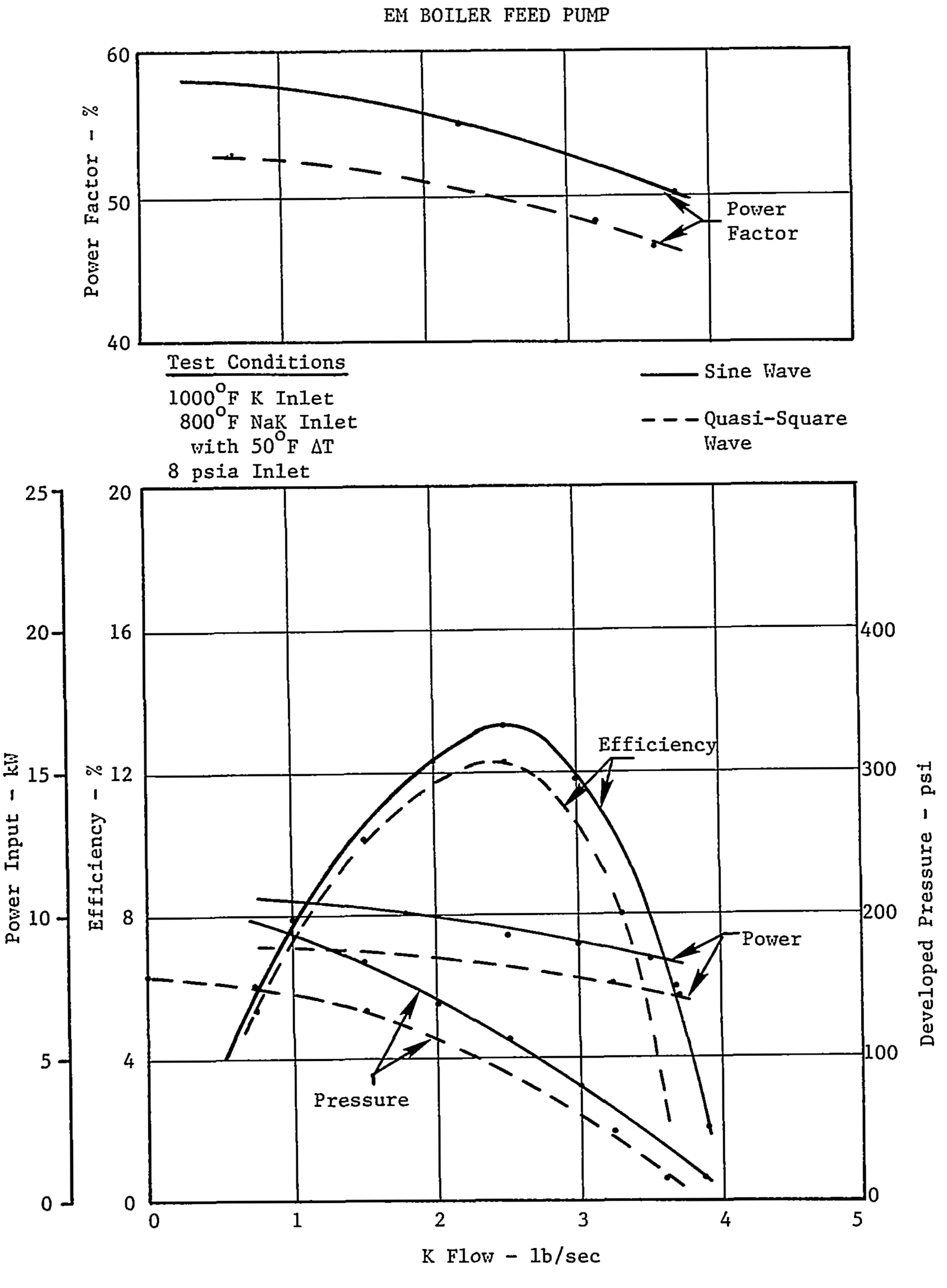


Figure 21. Comparison of Performance Results for Tests at 85 Volts, 60 Hz, with Sine and Quasi-Square Wave Input Power.

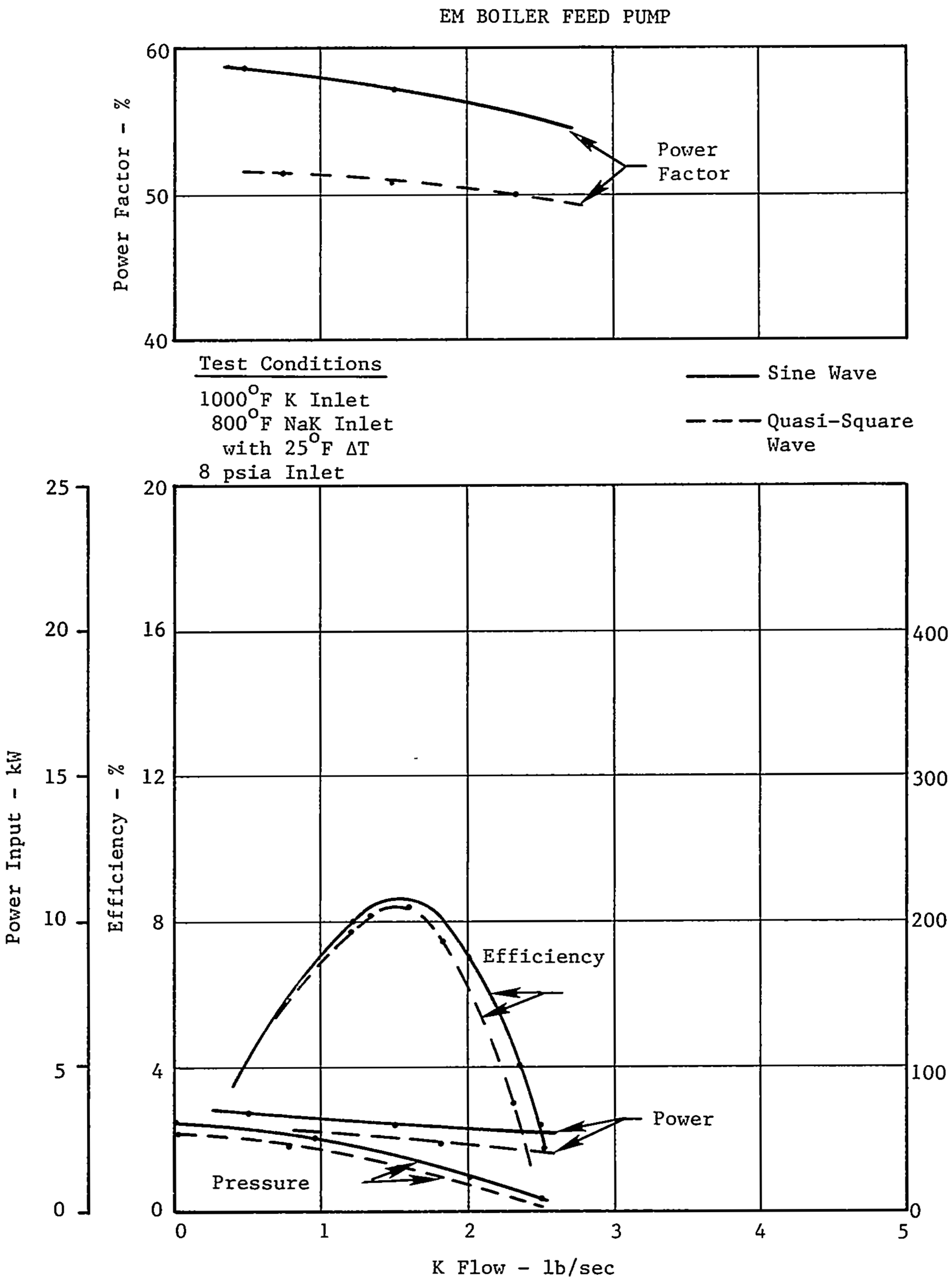


Figure 22. Comparison of Performance Results for Tests at 45 Volts, 60 Hz, with Sine and Quasi-Square Wave Input Power.

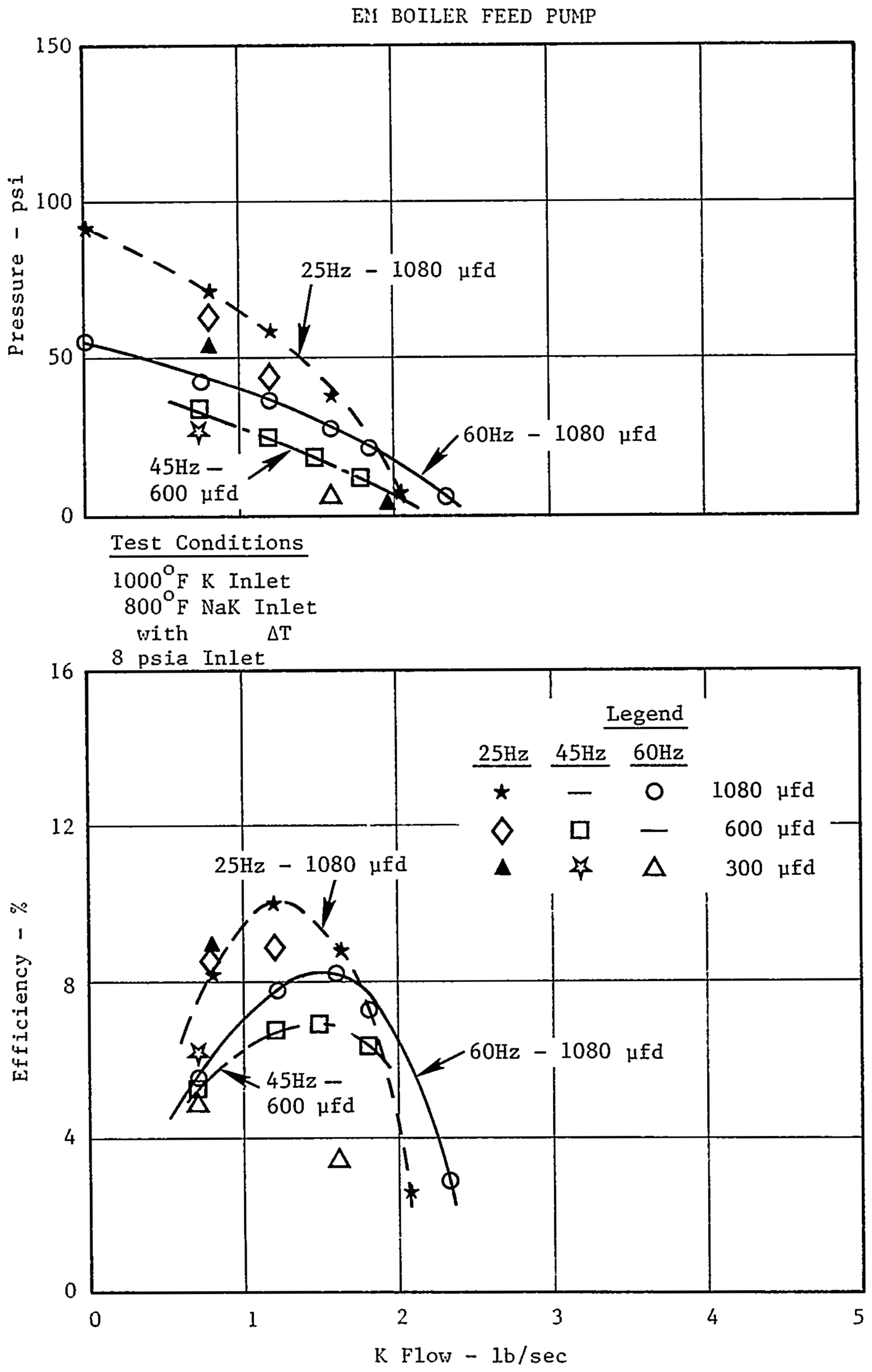


Figure 23. Performance Test Results for Input of 45 Volts with Quasi-Square Wave Power.

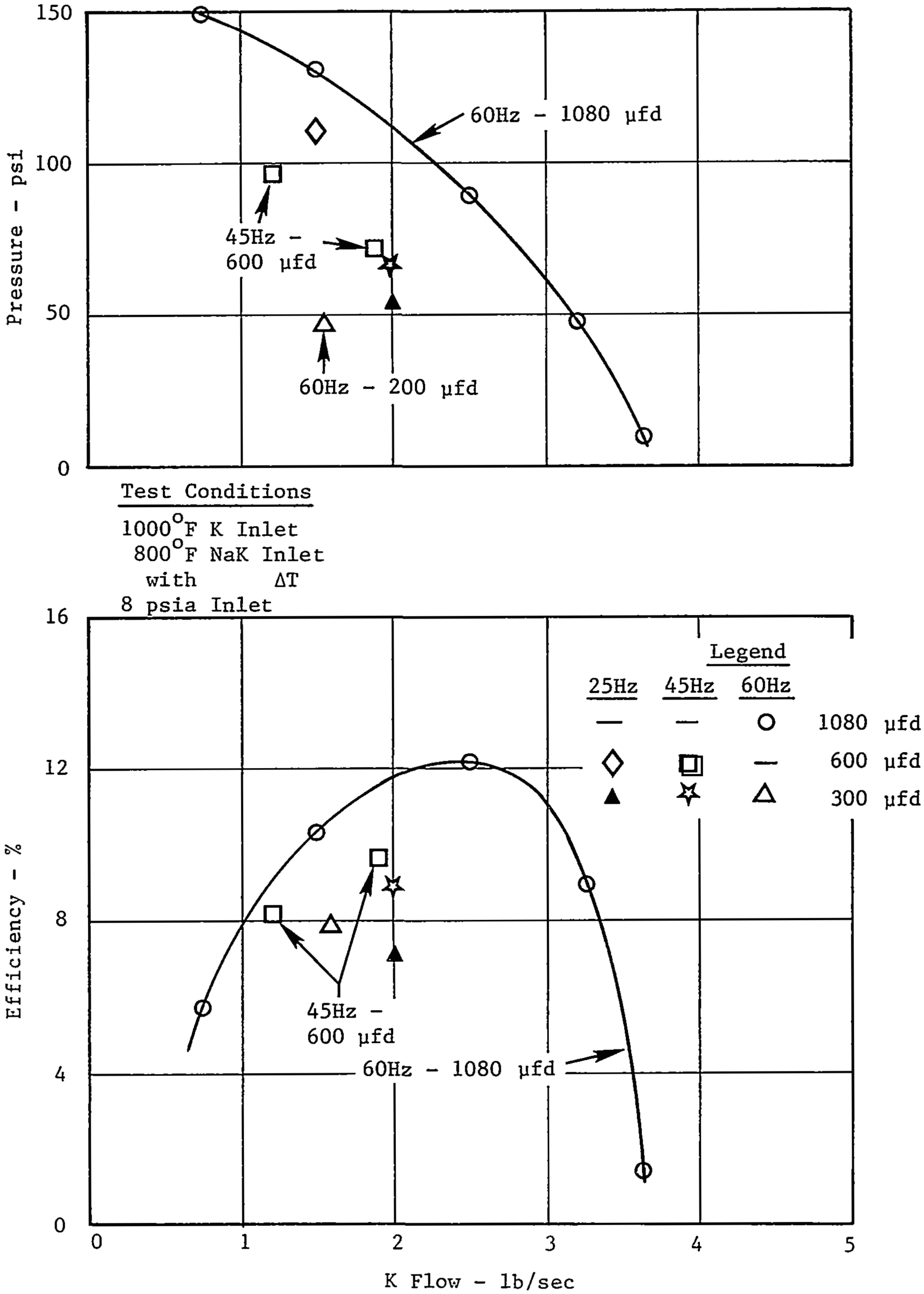
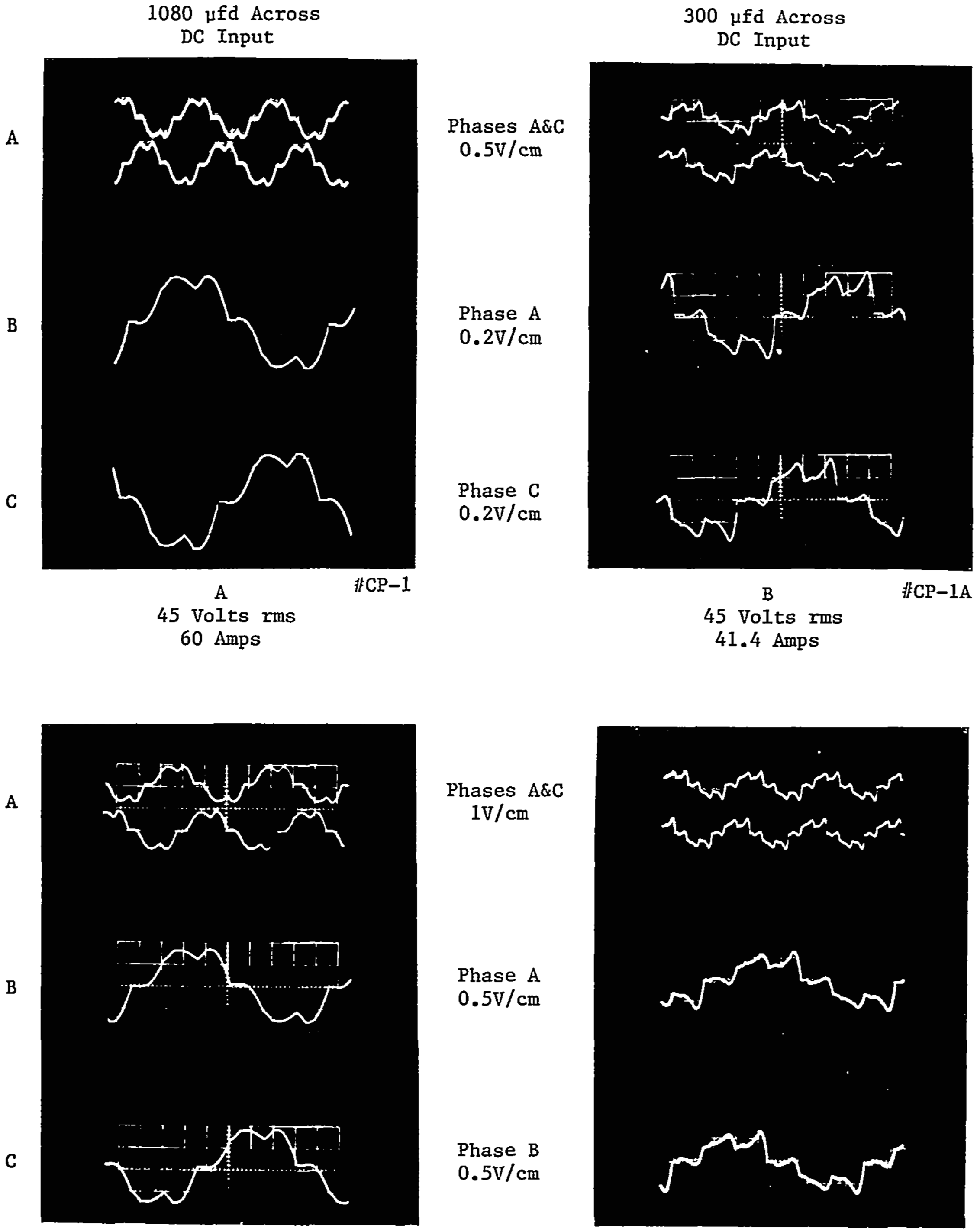


Figure 24. Performance Test Results for Input of 85 Volts with Quasi-Square Wave Power.



A #CP-1
45 Volts rms
60 Amps

B #CP-1A
45 Volts rms
41.4 Amps

C #CP-10
85 Volts rms
111.2 Amps

D #CP-3B
85 Volts rms
75.2 Amps

Note: Voltage traces are from drop across 1Ω resistor in secondary of 1000:5 line current transformers.

Figure 25. Oscilloscope of Traces of Current Waves with 60 Hz Quasi-Square Wave Power Supply.

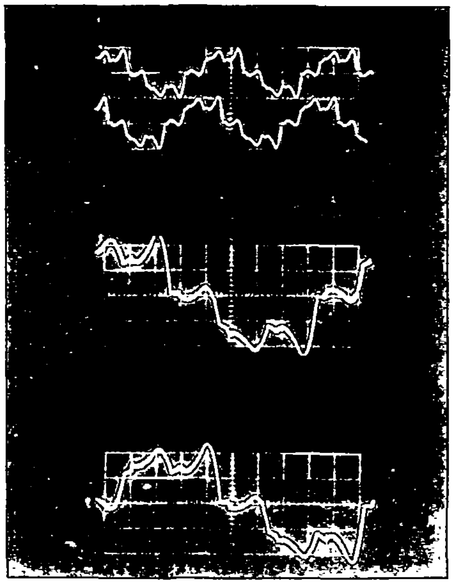
600 μfd Across
DC Input

300 μfd Across
DC Input

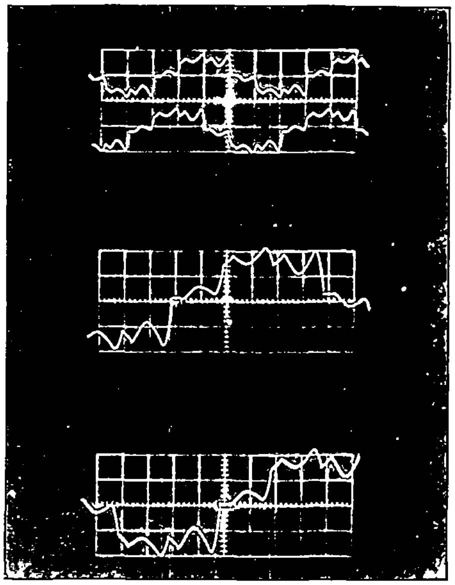
A — Phases A&C 0.5V/cm

B — Phase A 0.2V/cm

C — Phase C 0.2V/cm



A #CP-16
45 Volts rms, 45Hz
55 Amps



B #CP-16A
45 Volts rms, 45Hz
45 Amps

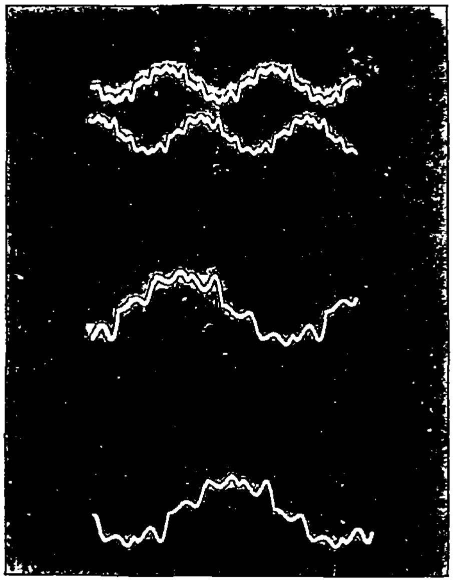
1080 μfd Across
DC Input

300 μfd Across
DC Input

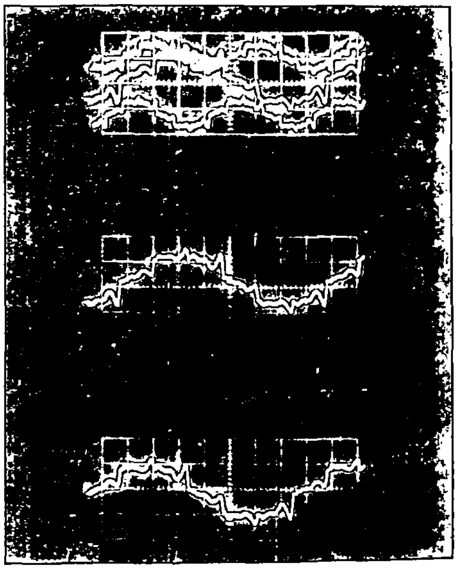
A — Phases A&C 1.0V/cm

B — Phase A 0.5V/cm

C — Phase C 0.5V/cm



C #CP-21
45 Volts rms, 25Hz
89 Amps



D #CP-21B
45 Volts rms, 25Hz
75 Amps

Note: Voltage traces are from drop across 1Ω resistor in secondary of 1000:5 line current transformers.

Figure 26. Oscilloscope Traces of Current Waves with 25 Hz and 45 Hz Quasi-Square Wave Power Supply.

TABLE I

DAILY ENDURANCE TEST DATA
WITH PUMP AT DESIGN POINT CONDITIONS*

Test No.	Power Input-KW	Average 3 Phase Voltage-V	Average 3 Phase Current-Amps	Actual Flow-#/sec	Actual Press-Psi	Calculated Pr.Factor	Calculated Efficiency-%
E-1	21.00	130.3	173.5	3.25	236	0.536	15.90
E-2	21.44	132.1	175.7	3.30	238	0.534	15.97
E-3	21.28	131.0	174.8	3.25	242	0.537	16.09
E-4	21.48	132.0	175.5	3.30	240	0.536	16.05
E-5	21.40	132.0	175.3	3.32	237	0.535	16.01
E-6	21.40	131.0	175.8	3.25	244	0.531	16.13
E-7	21.60	133.0	178.0	3.30	242	0.528	16.11
E-8	21.20	130.3	174.1	3.20	242	0.531	15.90
E-9	21.20	130.9	175.1	3.25	244	0.534	16.27
E-10	21.20	131.0	175.5	3.25	244	0.533	16.27
E-11	21.20	131.0	175.1	3.20	248	0.534	16.30
E-12	21.60	131.8	176.0	3.25	248	0.538	16.25
E-13	21.00	130.0	174.0	3.25	237	0.533	15.97
E-14	20.80	130.0	173.2	3.22	237	0.534	15.97
E-15	20.88	130.5	173.6	3.22	237	0.539	15.91
E-16	21.00	129.9	173.8	3.25	237	0.538	15.97
E-17	21.20	131.5	174.3	3.33	234	0.535	15.87
E-18	21.20	131.5	176.1	3.25	240	0.529	16.02
E-19	21.20	130.3	174.3	3.25	237	0.540	15.80
E-20	21.60	131.5	176.3	3.25	242	0.539	15.85
E-21	21.20	131.5	175.5	3.25	242	0.531	16.15
E-22	20.96	129.4	173.5	3.22	240	0.540	16.05
E-23	20.88	129.9	173.2	3.25	238	0.536	16.12
E-24	21.20	130.3	173.9	3.25	237	0.541	15.82
E-25	21.20	130.3	173.9	3.25	237	0.541	15.82
E-26	21.20	130.5	174.5	3.25	237	0.537	15.82
E-27	21.80	134.3	176.4	3.30	237	0.532	15.62
E-28	21.64	131.8	175.4	3.20	243	0.541	15.62
E-29	21.12	130.0	173.9	3.20	240	0.540	15.81
E-30	20.80	130.5	174.1	3.20	240	0.532	16.10
E-31	21.20	131.0	174.3	3.25	242	0.537	16.15
E-32	21.12	130.0	173.5	3.25	237	0.541	15.86
E-33	21.20	130.3	173.3	3.25	240	0.543	16.02
E-34	21.20	130.5	173.6	3.25	240	0.541	16.02
E-35	21.52	132.0	175.5	3.25	240	0.537	15.80
E-36	21.40	130.7	173.7	3.25	242	0.544	16.00
E-37	21.20	130.5	173.9	3.25	240	0.540	16.02
E-38	21.20	130.7	174.3	3.25	240	0.533	16.02
E-39	21.20	130.0	174.4	3.25	240	0.540	16.02
E-40	21.20	131.1	174.3	3.25	240	0.536	16.02
E-41	21.20	130.7	174.4	3.25	243	0.538	16.22
E-42	21.60	132.0	176.2	3.25	242	0.540	15.86
E-43	21.12	130.5	173.9	3.25	240	0.537	16.08
E-44	21.00	130.5	173.6	3.25	240	0.536	16.17

* Design Point Conditions - K inlet = 1000°F ± 15°F, NaK inlet = 800°F ± 10°F
NaK outlet = 850°F ± 10°F, Flow = 3.25 #/sec, Press = 240 psi

TABLE I (Continued)

Test No.	Power Input-KW	Average 3 Phase Voltage-V	Average 3 Phase Current-Amps	Actual Flow-#/sec	Actual Press.-Psi	Calculated Pr. Factor	Calculated Efficiency-%
E-45	21.00	130.5	174.0	3.25	240	0.534	16.17
E-46	20.88	130.5	173.7	3.25	240	0.533	16.26
E-47	21.12	130.5	173.7	3.25	240	0.539	16.08
E-48	21.20	130.5	174.1	3.25	240	0.539	16.01
E-49	21.60	132.2	175.7	3.25	240	0.537	15.70
E-50	21.20	131.0	174.1	3.25	240	0.537	16.01
E-51	21.20	131.0	173.9	3.25	240	0.538	16.01
E-52	21.20	130.7	173.7	3.25	240	0.539	16.01
E-53	21.20	131.0	173.9	3.25	240	0.538	16.01
E-54	21.20	130.3	174.1	3.25	240	0.541	16.01
E-55	21.60	131.6	176.0	3.30	242	0.539	16.40
E-56	21.00	130.7	174.0	3.25	240	0.534	16.20
E-57	21.00	130.3	173.7	3.25	240	0.536	16.17
E-58	21.12	131.0	174.1	3.25	240	0.535	16.07
E-59	21.20	130.8	173.9	3.25	240	0.539	16.02
E-60	21.20	130.7	174.4	3.30	242	0.538	16.40
E-61	21.20	130.8	174.0	3.25	240	0.538	16.02
E-62	21.20	131.7	174.9	3.30	240	0.532	16.26
E-63	21.20	131.7	174.9	3.30	240	0.532	16.26
E-64	21.20	130.8	174.1	3.25	240	0.538	16.02
E-65	21.20	130.7	174.2	3.25	240	0.538	16.02
E-66	21.12	130.8	174.1	3.25	240	0.536	16.08
E-67	20.80	129.5	172.8	3.25	240	0.537	16.33
E-68	21.20	130.8	174.1	3.25	240	0.538	16.02
E-69	21.20	131.5	174.2	3.25	243	0.535	16.22
E-70	21.00	130.0	173.2	3.25	240	0.539	16.17
E-71	20.88	130.1	173.7	3.25	240	0.534	16.26
E-72	21.00	130.0	173.3	3.20	244	0.540	16.20
E-73	21.00	130.0	173.3	3.20	240	0.540	15.95
E-74	20.80	129.5	173.2	3.25	240	0.536	16.35
E-75	21.12	130.3	174.0	3.25	240	0.537	16.07
E-76	21.20	131.1	174.5	3.25	241	0.535	16.08
E-77	21.28	131.7	175.2	3.25	241	0.533	16.02
E-78	21.20	131.7	175.2	3.25	241	0.531	16.08
E-79	21.00	130.0	173.2	3.25	240	0.540	16.17
E-80	20.80	130.0	173.8	3.25	240	0.532	16.33
E-81	20.80	130.0	173.6	3.25	240	0.533	16.33
E-82	21.12	129.8	174.0	3.25	240	0.541	16.08
E-83	21.00	130.0	173.6	3.25	240	0.538	16.17
E-84	21.20	131.0	174.4	3.25	240	0.536	16.02
E-85	20.80	129.8	173.3	3.25	240	0.535	16.33
E-86	20.76	129.5	173.3	3.25	240	0.534	16.36
E-87	21.00	130.5	173.8	3.25	240	0.533	16.17
E-88	21.12	130.5	174.0	3.25	240	0.538	16.08
E-89	21.00	130.0	173.6	3.25	240	0.538	16.17
E-90	21.20	130.7	174.4	3.25	240	0.538	16.02

TABLE I (Continued)

Test No.	Power Input-KW	Average 3 Phase Voltage-V	Average 3 Phase Current-Amps	Actual Flow-#/sec	Actual Press.-Psi	Calculated Pr. Factor	Calculated Efficiency-%
E-91	21.00	130.0	173.7	3.25	240	0.537	16.17
E-92	21.20	130.0	173.6	3.25	241	0.543	16.08
E-93	20.80	129.5	173.2	3.25	240	0.536	16.33
E-94	20.80	129.5	173.2	3.25	240	0.536	16.33
E-95	21.00	129.8	173.7	3.25	241	0.538	16.24
E-96	20.80	129.5	172.3	3.25	240	0.539	16.32
E-97	20.80	129.8	173.0	3.25	240	0.536	16.33
E-98	21.00	131.0	173.6	3.25	240	0.534	16.17
E-99	21.12	130.3	174.0	3.25	241	0.539	16.15
E-100	21.20	131.0	174.2	3.25	241	0.537	16.08
E-101	21.20	130.3	174.1	3.25	240	0.540	16.02
E-102	21.92	134.0	177.8	3.30	240	0.530	15.73
E-103	21.68	133.0	176.6	3.35	241	0.534	16.21
E-104	21.60	133.0	176.4	3.30	241	0.533	16.02
E-105	21.60	132.8	176.4	3.25	240	0.530	15.85
E-106	21.60	133.0	176.8	3.25	243	0.531	15.94
E-107	20.80	129.5	174.0	3.20	241	0.534	16.17
E-108	20.80	130.0	172.4	3.20	239	0.536	16.04
E-109	21.20	131.0	174.8	3.25	240	0.535	15.99
E-110	21.00	130.5	173.6	3.25	240	0.536	16.17
E-111	21.20	131.0	173.6	3.20	240	0.539	15.77
E-112	20.72	129.5	172.8	3.20	236	0.535	15.87
E-113	20.80	129.0	171.2	3.20	244	0.539	16.32
E-114	21.20	130.0	174.0	3.25	242	0.542	16.15
E-115	21.00	130.0	173.2	3.20	240	0.539	15.92
E-116	20.80	130.0	173.6	3.20	240	0.533	16.08
E-117	21.20	131.0	174.0	3.20	240	0.538	15.77
E-118	21.20	131.0	178.0	3.25	242	0.526	16.16
E-119	20.80	130.0	173.2	3.25	240	0.534	16.33
E-120	20.80	130.0	173.4	3.25	240	0.533	16.33
E-121	20.88	131.0	174.0	3.25	240	0.529	16.26
E-122	20.88	129.7	173.7	3.25	240	0.536	16.26
E-123	21.00	130.3	173.7	3.25	240	0.536	16.17
E-124	21.00	130.0	173.6	3.25	240	0.538	16.17
E-125	20.88	130.0	173.6	3.25	240	0.535	16.26
E-126	20.84	130.5	173.3	3.25	240	0.533	16.29
E-127	21.12	130.7	173.7	3.25	240	0.538	16.08
E-128	20.60	130.0	173.3	3.25	240	0.536	16.24
E-129	20.60	130.0	172.0	3.30	241	0.533	16.80
E-130	20.24	127.4	170.8	3.25	239	0.539	16.74
E-131	20.40	128.0	171.2	3.20	240	0.538	16.39
E-132	20.20	128.0	170.0	3.20	240	0.537	16.55
E-133	20.72	130.0	172.0	3.25	240	0.536	16.39
E-134	20.80	130.0	172.0	3.20	240	0.538	16.08
E-135	20.80	130.0	171.6	3.25	240	0.539	16.33
E-136	20.80	130.0	172.0	3.20	240	0.538	16.08

TABLE I (Continued)

Test No.	Power Input-KW	Average 3 Phase Voltage-V	Average 3 Phase Current-Amps	Actual Flow-#/sec	Actual Press.-Psi	Calculated Pr. Factor	Calculated Efficiency-%
E-137	20.80	130.0	172.0	3.20	240	0.538	16.08
E-138	21.00	131.0	173.3	3.25	240	0.535	16.19
E-139	21.20	129.5	171.2	3.23	239	0.553	15.85
E-140	20.92	131.2	173.2	3.25	240	0.533	16.23
E-141	21.12	131.2	173.5	3.25	240	0.536	16.08
E-142	20.80	129.5	172.0	3.20	240	0.540	16.08
E-143	20.60	130.0	171.3	3.20	240	0.540	16.08
E-144	20.80	130.5	172.5	3.25	240	0.534	16.33
E-145	20.80	130.0	172.0	3.20	240	0.538	16.08
E-146	21.20	131.5	174.0	3.23	244	0.536	16.18
E-147	20.80	130.0	172.3	3.25	240	0.537	16.33
E-148	20.80	130.0	172.4	3.20	240	0.536	16.08
E-149	20.88	130.5	172.8	3.20	240	0.535	16.01
E-150	20.80	130.5	172.7	3.20	240	0.533	16.08
E-151	20.80	131.0	172.3	3.20	240	0.533	16.08
E-152	21.00	131.2	173.3	3.25	240	0.534	16.17
E-153	21.04	132.0	173.9	3.28	240	0.530	16.29
E-154	20.80	130.0	172.0	3.23	240	0.538	16.22
E-155	21.00	131.0	172.8	3.25	240	0.536	16.17
E-156	20.60	130.0	171.2	3.25	243	0.535	16.64
E-157	20.80	130.0	171.9	3.25	239	0.538	16.29
E-158	20.40	128.9	170.7	3.25	240	0.536	16.64
E-159	20.40	128.8	170.5	3.20	240	0.537	16.39
E-160	20.60	129.0	171.2	3.20	240	0.539	16.23
E-161	20.52	130.2	172.5	3.25	240	0.528	16.55
E-162	20.80	130.5	172.8	3.28	240	0.533	16.47
E-163	20.60	129.3	171.6	3.20	240	0.535	16.23
E-164	20.60	129.8	172.0	3.25	240	0.533	16.48
E-165	20.56	128.7	171.1	3.20	240	0.540	16.26
E-166	20.40	128.7	170.4	3.18	240	0.538	16.29
E-167	20.40	128.7	170.9	3.17	240	0.536	16.23
E-168	20.40	129.5	171.1	3.18	240	0.532	16.29
E-169	21.20	131.5	173.3	3.25	240	0.537	16.02
E-170	20.80	129.5	171.7	3.25	240	0.541	16.32
E-171	20.32	128.0	170.1	3.17	240	0.539	16.30
E-172	20.00	127.3	169.7	3.16	240	0.535	16.50
E-173	20.80	131.0	173.3	3.30	240	0.529	16.58
E-174	20.00	129.0	170.8	3.16	240	0.525	16.51
E-175	20.00	129.2	170.9	3.18	241	0.524	16.68
E-176	21.20	132.8	175.6	3.30	240	0.526	16.26
E-177	20.80	130.5	174.0	3.28	240	0.529	16.40
E-178	20.80	129.5	171.4	3.25	240	0.542	16.30
E-179	20.80	131.0	173.5	3.25	240	0.529	16.33
E-180	20.40	129.6	172.3	3.25	240	0.528	16.65
E-181	←		No Data Recorded		→		
E-182	←		No Data Recorded		→		

TABLE I (Continued)

Test No.	Power Input-KW	Average 3 Phase Voltage-V	Average 3 Phase Current-Amps	Actual Flow-#/sec	Actual Press.-Psi	Calculated Pr. Factor	Calculated Efficiency-%
E-183	20.40	129.5	171.1	3.25	240	0.532	16.64
E-184	20.40	129.5	170.8	3.30	240	0.533	16.80
E-185	20.72	131.5	173.5	3.32	240	0.525	16.74
E-186	20.64	131.5	172.9	3.30	240	0.525	16.71
E-187	21.04	131.5	173.3	3.30	240	0.534	16.39
E-188	20.56	129.5	172.0	3.30	240	0.534	16.77
E-189	20.48	130.0	170.8	3.30	240	0.531	16.82
E-190	20.80	131.5	172.8	3.31	240	0.529	16.65
E-191	20.08	128.3	170.0	3.23	240	0.533	16.84
E-192	20.32	129.4	170.9	3.28	239	0.531	16.81
E-193	20.40	129.2	170.5	3.25	241	0.535	16.71
E-194	21.12	131.7	174.0	3.25	241	0.533	16.14
E-195	20.96	131.1	173.2	3.24	241	0.534	16.21
E-196	21.12	132.1	174.5	3.28	240	0.529	16.23
E-197	20.88	131.8	173.6	3.25	240	0.528	16.25
E-198	20.96	131.7	173.6	3.25	240	0.530	16.20
E-199	20.96	131.0	173.1	3.24	241	0.534	16.19
E-200	21.00	132.0	174.2	3.25	241	0.528	16.20
E-201	21.60	131.0	173.3	3.24	241	0.550	15.72
E-202	21.20	132.7	175.1	3.30	240	0.527	16.26
E-203	21.08	131.6	174.0	3.30	240	0.532	16.36
E-204	21.24	133.3	175.2	3.30	240	0.526	16.23
E-205	20.80	130.7	172.9	3.23	240	0.532	16.22
E-206	20.40	128.7	171.1	3.20	240	0.535	16.39
E-207	20.64	130.5	172.4	3.25	240	0.530	16.45
E-208	20.80	131.0	171.2	3.20	240	0.536	16.07
E-209	21.20	132.9	175.0	3.25	241	0.526	16.05
E-210	21.00	132.5	174.3	3.23	241	0.526	16.10
E-211	21.20	132.7	174.5	3.25	240	0.529	16.02
E-212	21.12	132.2	174.7	3.25	240	0.529	16.08
E-213	20.40	128.7	171.1	3.16	240	0.535	16.19
E-214	20.84	131.1	173.1	3.24	240	0.531	16.24
E-215	20.80	130.5	173.1	3.23	241	0.532	16.29
E-216	20.48	129.3	171.9	3.20	240	0.533	16.33
E-217	20.64	130.3	172.5	3.20	240	0.531	16.20
E-218	20.80	132.0	172.0	3.25	240	0.530	16.33
E-219	20.80	131.0	171.2	3.20	240	0.536	16.08
E-220	20.08	128.7	169.9	3.16	234	0.531	15.96
E-221	20.80	130.2	172.2	3.20	240	0.536	16.08
E-222	20.80	130.0	172.0	3.23	240	0.538	16.23
E-223	20.76	131.0	173.2	3.18	240	0.529	16.01
E-224	20.52	130.0	172.4	3.18	240	0.529	16.19
E-225	21.12	131.8	173.9	3.30	240	0.533	16.33
E-226	20.88	130.8	173.5	3.23	240	0.531	16.16
E-227	20.80	130.9	173.1	3.23	241	0.531	16.26
E-228	21.20	132.4	174.9	3.25	241	0.529	16.05
E-229	20.92	131.0	173.5	3.23	241	0.533	16.20
E-230	20.76	130.7	172.8	3.23	241	0.531	16.32

TABLE I (Continued)

Test No.	Power Input-KW	Average 3 Phase Voltage-V	Average 3 Phase Current-Amps	Actual Flow-#/sec	Actual Press.-Psi	Calculated Pr. Factor	Calculated Efficiency-%
E-231	21.24	133.5	175.2	3.25	240	0.525	15.99
E-232	20.40	129.0	171.6	3.20	240	0.533	16.39
E-233	20.88	131.7	173.6	3.24	240	0.528	16.21
E-234	20.88	131.3	173.5	3.25	240	0.530	16.26
E-235	20.80	130.7	172.8	3.23	240	0.532	16.22
E-236	20.80	130.8	172.7	3.25	240	0.532	16.30
E-237	20.40	128.8	170.3	3.20	234	0.539	15.91
E-238	20.60	130.7	172.1	3.25	234	0.531	16.03
E-239	21.24	132.7	175.4	3.30	240	0.527	16.23
E-240	20.80	130.7	173.2	3.30	240	0.531	16.57
E-241	20.80	130.7	173.5	3.25	240	0.530	16.33
E-242	21.04	132.0	174.7	3.30	240	0.527	16.39
E-243	20.92	131.7	174.0	3.28	240	0.528	16.39
E-244	20.64	130.5	172.4	3.28	240	0.530	16.60
E-245	20.84	131.2	173.3	3.28	240	0.530	16.46
E-246	21.00	131.6	173.6	3.25	240	0.531	16.17
E-247	20.80	131.3	173.0	3.25	240	0.530	16.33
E-248	20.64	129.7	172.0	3.25	240	0.535	16.45
E-249	20.60	130.0	172.4	3.25	240	0.531	16.48
E-250	20.40	128.7	171.1	3.20	240	0.536	16.39
E-251	20.40	129.3	170.9	3.25	240	0.534	16.65
E-252	20.48	130.0	172.5	3.25	240	0.528	16.58
E-253	20.48	129.3	172.1	3.25	240	0.532	16.58
E-254	20.84	131.3	173.9	3.30	240	0.528	16.54
E-255	20.80	129.8	171.8	3.22	240	0.540	16.18
E-256	20.76	130.7	172.9	3.25	240	0.533	16.36
E-257	20.80	131.0	173.3	3.30	240	0.529	16.58
E-258	20.40	129.8	171.6	3.20	240	0.529	16.39
E-259	21.20	132.8	175.2	3.30	240	0.527	16.26
E-260	20.84	130.7	172.7	3.28	240	0.534	16.46
E-261	20.80	130.3	172.7	3.25	240	0.534	16.33
E-262	20.72	130.8	172.7	3.28	240	0.530	16.54
E-263	21.12	131.7	174.1	3.30	240	0.532	16.33
E-264	21.08	131.8	174.2	3.30	240	0.531	16.36
E-265	20.80	130.5	172.0	3.23	244	0.536	16.50
E-266	20.20	129.0	170.0	3.15	244	0.532	16.57
E-267	21.08	132.8	174.1	3.30	240	0.527	16.36
E-268	20.76	130.5	172.3	3.28	240	0.534	16.51
E-269	20.40	129.7	171.7	3.25	240	0.529	16.65
E-270	20.20	129.3	171.6	3.20	240	0.526	16.55
E-271	20.48	129.7	171.2	3.23	240	0.533	16.48
E-272	20.44	129.2	171.5	3.23	240	0.533	16.51
E-273	20.40	129.7	171.5	3.24	240	0.530	16.59
E-274	20.60	130.5	172.3	3.25	240	0.530	16.49
E-275	20.88	131.2	173.5	3.25	240	0.530	16.26
E-276	20.00	127.0	169.2	3.20	240	0.538	16.72
E-277	20.60	130.0	172.4	3.30	240	0.528	16.74

TABLE I (Continued)

Test No.	Power Input-KW	Average 3 Phase		Actual		Calculated	
		Voltage-V	Current-Amps	Flow-#/sec	Press.-Psi	Pr. Factor	Efficiency-%
E-278	20.84	131.3	172.9	3.28	240	0.531	16.46
E-279	20.40	129.0	171.0	3.25	240	0.533	16.65
E-280	20.40	129.5	171.7	3.28	240	0.530	16.80
E-281	20.60	129.7	172.0	3.28	240	0.534	16.65
E-282	20.76	130.7	172.5	3.25	240	0.532	16.36
E-283	20.72	129.8	171.7	3.25	240	0.537	16.39
E-284	20.80	130.5	172.9	3.25	240	0.533	16.33
E-285	21.08	130.7	173.7	3.25	240	0.533	16.11
E-286	20.84	130.9	172.8	3.25	240	0.533	16.30
E-287	20.96	131.6	173.5	3.25	240	0.530	16.20
E-288	21.00	131.6	173.6	3.25	240	0.532	16.17
E-289	20.88	131.2	173.3	3.25	240	0.531	16.26
E-290	20.80	130.5	172.4	3.23	240	0.534	16.23
E-291	20.60	129.4	171.6	3.23	240	0.538	16.38
E-292	20.80	131.0	173.6	3.23	240	0.529	16.23
E-293	20.88	131.3	173.2	3.25	240	0.530	16.26
E-294	21.20	132.1	174.4	3.25	240	0.532	16.02
E-295	21.20	132.3	174.5	3.30	240	0.531	16.26
E-296	20.96	131.7	173.9	3.28	240	0.529	16.36
E-297	20.92	131.7	174.0	3.30	240	0.528	16.48
E-298	20.80	130.3	173.3	3.23	240	0.533	16.22
E-299	20.80	130.7	172.8	3.23	240	0.532	16.22
E-300	20.44	128.8	171.3	3.18	240	0.535	16.25
E-301	20.64	130.2	172.4	3.23	240	0.532	16.35
E-302	21.00	131.5	173.5	3.25	240	0.532	16.17
E-303	21.12	131.8	174.0	3.25	240	0.532	16.08
E-304	20.64	130.2	172.3	3.20	240	0.532	16.20
E-305	20.48	129.3	171.6	3.20	240	0.534	16.32
E-306	20.80	130.7	173.1	3.23	240	0.532	16.22
E-307	20.40	128.7	170.8	3.20	240	0.536	16.39
E-308	21.08	131.8	173.8	3.23	240	0.532	16.01
E-309	20.88	131.3	173.7	3.23	240	0.529	16.16
E-310	21.20	133.0	174.7	3.28	240	0.527	16.17
E-311	20.92	131.6	173.7	3.25	240	0.529	16.23
E-312	21.16	131.9	174.1	3.25	240	0.533	16.05
E-313	21.20	132.9	175.3	3.25	240	0.526	16.02
E-314	21.12	131.9	174.3	3.25	240	0.531	16.08
E-315	21.00	131.8	174.0	3.25	240	0.529	16.17
E-316	21.16	132.1	173.9	3.25	240	0.533	16.05
E-317	21.00	131.8	173.9	3.25	240	0.530	16.17
E-318	20.52	129.7	169.6	3.18	240	0.539	16.19
E-319	20.80	130.5	172.3	3.20	240	0.535	16.07
E-320	21.20	131.8	174.0	3.23	240	0.534	15.92
E-321	21.00	131.5	173.7	3.25	240	0.531	16.17
E-322	21.16	132.3	174.4	3.25	240	0.530	16.05
E-323	20.84	131.3	173.6	3.25	240	0.529	16.30
E-324	20.40	129.2	174.0	3.25	240	0.525	16.39

TABLE I (Continued)

Test No.	Power Input-KW	Average 3 Phase Voltage-V	Average 3 Phase Current-Amps	Actual Flow-#/sec	Actual Press.-Psi	Calculated Pr. Factor	Calculated Efficiency-%
E-325	20.60	129.5	172.1	3.18	240	0.534	16.13
E-326	20.80	131.3	172.3	3.32	234	0.532	16.12
E-327	20.80	129.8	172.7	3.23	240	0.536	16.23
E-328	21.00	132.0	174.3	3.25	240	0.528	16.17
E-329	20.88	131.4	173.6	3.25	240	0.529	16.26
E-330	20.40	129.5	171.2	3.20	240	0.532	16.39
E-331	20.44	128.8	171.3	3.18	240	0.535	16.26
E-332	20.80	131.0	173.3	3.25	240	0.530	16.33
E-333	20.80	130.8	172.8	3.25	240	0.532	16.33
E-334	21.16	132.5	174.1	3.30	240	0.530	16.30
E-335	20.80	131.2	172.8	3.25	240	0.530	16.33
E-336	20.84	131.5	173.6	3.25	240	0.528	16.30
E-337	20.40	128.7	171.1	3.23	238	0.535	16.41
E-338	20.80	130.5	173.0	3.26	240	0.533	16.38
E-339	20.20	127.3	169.7	3.20	240	0.535	16.72
E-340	20.40	129.3	171.2	3.18	240	0.533	16.29
E-341	20.56	130.3	172.1	3.25	240	0.530	16.52
E-342	20.60	130.2	172.5	3.25	240	0.530	16.49
E-343	20.88	131.8	174.0	3.30	240	0.526	16.51
E-344	21.04	131.8	173.9	3.25	240	0.531	16.14
E-345	20.80	131.3	173.3	3.25	240	0.528	16.33
E-346	20.84	131.3	173.1	3.25	240	0.530	16.29
E-347	20.88	131.6	173.6	3.25	240	0.528	16.26
E-348	20.88	131.9	174.3	3.25	240	0.525	16.26
E-349	20.80	130.8	173.3	3.25	240	0.530	16.33
E-350	20.72	130.7	172.8	3.25	240	0.530	16.39
E-351	20.60	131.2	173.2	3.23	240	0.524	16.38
E-352	20.60	130.8	172.8	3.26	240	0.527	16.53
E-353	20.80	131.2	173.3	3.30	240	0.529	16.58
E-354	20.88	131.2	173.3	3.27	240	0.531	16.36
E-355	20.40	129.3	171.7	3.23	240	0.531	16.54
E-356	20.76	131.1	173.5	3.25	240	0.528	16.36
E-357	20.76	130.7	172.9	3.25	240	0.531	16.36
E-358	20.60	130.4	172.5	3.25	240	0.529	16.49
E-359	20.60	130.4	172.5	3.25	240	0.529	16.49
E-360	20.60	130.3	172.5	3.25	240	0.530	16.49
E-361	20.76	130.6	172.8	3.25	240	0.532	16.36
E-362	20.80	130.9	172.9	3.25	240	0.531	16.33
E-363	20.68	130.7	172.9	3.30	240	0.529	16.67
E-364	20.80	130.8	173.2	3.30	240	0.531	16.58
E-365	20.40	129.4	171.2	3.22	240	0.533	16.50
E-366	20.40	129.4	171.7	3.22	240	0.531	16.50
E-367	20.40	129.3	171.3	3.22	240	0.531	16.50
E-368	20.60	130.7	173.0	3.25	240	0.527	16.49
E-369	20.40	128.8	170.9	3.20	240	0.536	16.39
E-370	20.76	131.0	173.3	3.30	240	0.529	16.61

TABLE I (Continued)

Test No.	Power Input-KW	Average 3 Phase Voltage-V	Average 3 Phase Current-Amps	Actual Flow-#/sec	Actual Press.-Psi	Calculated Pr. Factor	Calculated Efficiency-%
E-371	20.80	131.0	173.3	3.30	240	0.529	16.58
E-372	20.40	130.0	172.0	3.23	240	0.530	16.54
E-373	20.40	129.7	172.1	3.25	240	0.528	16.65
E-374	20.40	129.2	171.3	3.23	240	0.533	16.54
E-375	20.72	130.4	172.8	3.25	240	0.532	16.39
E-376	20.72	130.5	172.7	3.25	240	0.532	16.39
E-377	20.84	131.2	173.2	3.25	240	0.530	16.30
E-378	20.60	130.2	173.9	3.25	240	0.526	16.48
E-379	20.68	130.2	172.5	3.25	240	0.532	16.42
E-380	20.80	131.2	173.3	3.25	240	0.529	16.33
E-381	20.60	130.5	172.5	3.23	240	0.529	16.38
E-382	21.16	132.3	174.8	3.30	240	0.529	16.29
E-383	20.84	131.3	174.1	3.30	240	0.527	16.55
E-384	20.76	130.4	173.1	3.25	241	0.532	16.43
E-385	20.72	130.4	172.5	3.25	241	0.532	16.46
E-386	20.00	127.8	170.0	3.18	240	0.532	16.61
E-387	20.60	130.3	172.1	3.23	240	0.531	16.38
E-388	20.64	130.3	172.9	3.23	240	0.530	16.35
E-389	20.44	130.3	172.3	3.23	240	0.526	16.51
E-390	20.80	131.0	174.1	3.30	240	0.527	16.58
E-391	20.80	130.7	173.2	3.30	240	0.531	16.58
E-392	20.88	131.6	173.6	3.30	240	0.528	16.58
E-393	20.68	130.4	172.4	3.25	240	0.532	16.42
E-394	20.72	130.4	172.8	3.25	240	0.532	16.39
E-395	20.72	130.6	172.9	3.25	240	0.530	16.39
E-396	20.40	129.3	171.3	3.23	240	0.532	16.54
E-397	20.68	130.2	172.3	3.23	240	0.533	16.32
E-398	20.92	131.7	173.6	3.30	240	0.529	16.48
E-399	20.72	130.3	172.9	3.30	240	0.532	16.64
E-400	20.68	129.3	171.3	3.30	240	0.544	16.67
E-401	20.76	131.0	173.1	3.30	240	0.530	16.61
E-402	20.72	130.2	172.3	3.25	240	0.534	16.39
E-403	20.60	130.2	172.1	3.25	240	0.531	16.49
E-404	20.72	130.4	173.2	3.25	240	0.530	16.39
E-405	20.72	130.5	172.9	3.30	240	0.531	16.64
E-406	20.40	129.8	172.1	3.23	240	0.528	16.54
E-407	20.40	129.0	171.2	3.23	240	0.534	16.54
E-408	20.36	128.3	170.8	3.23	240	0.537	16.54
E-409	20.48	130.0	172.4	3.27	240	0.528	16.68
E-410	20.40	129.0	171.3	3.22	240	0.534	16.49
E-411	20.80	131.2	174.5	3.30	240	0.527	16.58
E-412	20.84	131.2	173.5	3.25	240	0.529	16.30
E-413	20.60	130.5	172.7	3.25	240	0.528	16.49
E-414	20.40	129.2	171.2	3.23	240	0.533	16.54
E-415	20.48	130.2	172.0	3.25	240	0.529	16.58
E-416	20.88	131.7	173.5	3.30	240	0.528	16.51

TABLE I (Continued)

Test No.	Power Input-KW	Average 3 Phase Voltage-V	Average 3 Phase Current-Amps	Actual Flow-#/sec	Actual Press.-Psi	Calculated Pr. Factor	Calculated Efficiency-%
E-417	20.64	130.7	172.9	3.23	240	0.528	16.35
E-418	20.80	131.3	173.3	3.23	240	0.528	16.23
E-419	20.44	129.0	171.3	3.23	240	0.535	16.51
E-420	20.80	130.7	172.5	3.27	240	0.533	16.43
E-421	20.80	131.2	173.6	3.25	240	0.528	16.33
10,000 HOUR ENDURANCE TEST COMPLETED - EXTRA TESTS (895 HOURS) LISTED BELOW							
X-1	21.20	132.8	175.7	3.25	240	0.525	16.00
X-2	21.20	132.2	174.9	3.25	240	0.530	16.01
X-3	20.72	130.3	172.4	3.25	240	0.533	16.39
X-4	21.00	132.3	173.9	3.25	240	0.528	16.16
X-5	20.48	130.2	172.3	3.25	240	0.528	16.57
X-6	20.80	131.0	172.9	3.25	240	0.531	16.32
X-7	20.92	131.9	174.3	3.25	240	0.526	16.21
X-8	20.80	131.5	173.5	3.25	240	0.527	16.33
X-9	20.84	131.4	173.7	3.25	240	0.528	16.30
X-10	20.88	131.6	174.0	3.25	240	0.527	16.26
X-11	20.64	130.6	172.3	3.25	240	0.530	16.45
X-12	21.00	132.1	174.4	3.25	240	0.527	16.17
X-13	20.92	131.6	173.6	3.25	240	0.529	16.23
X-14	21.00	132.0	174.4	3.25	240	0.527	16.17
X-15	21.00	131.8	174.3	3.25	240	0.528	16.17
X-16	21.00	131.5	174.5	3.25	240	0.529	16.17
X-17	20.84	131.1	173.1	3.25	240	0.531	16.30
X-18	20.72	130.5	172.8	3.25	240	0.531	16.39

TABLE II

ANALYSIS OF LIQUID METAL SAMPLES FROM PUMP TEST LOOPS - Impurities in Parts Per Million (ppm)

	Potassium							NaK		
Sample No.	2589	2708	2761	2824	2862	2929	3154	2763	2766	3186
Date	9/29/69	11/10/69	12/23/69	2/19/70	3/31/70	5/11/70	10/27/70	12/24/69	1/5/70	12/10/70
Hours on Endurance Test	1000	2007	3036	4107	5058	6040	10,000	3036	3036	10,895
Impurity										
O_2	6,7	5,6	3,4	4	4,4	5,6	9,11	22,28	21,25	19,26
C	49	58	38	44	48	30	11,12	33	–	24
Ag	<2	<2	<2	–	–	<2	<2	–	–	2
Al	10	6	<12			<2	<20			6
B	<20	<20	<20			<20	<20			<20
Ba	<22	<20	<20			<20	<20			<20
Be	<2	<2	<2			<2	<2			<2
Ca	2	2	2			2	4			–
Cb	<20	<20	<20			<20	<20			–
Co	<2	<2	<2			<2	<10			–
Cr	<6	<6	<6			<6	<10			2
Cu	<2	<2	<2			<2	<2			–
Fe	12	4	2			6	<2			2
Li	<2	20	<2			<2	<2			<2
Mg	<2	<2	<2			<2	<2			<2
Mn	<2	<2	<2			<2	<2			<2
Mo	<6	<6	6			<6	<10			<6
Ni	<6	<6	<6			<6	<6			<6
Pb	<10	<10	<10			<10	<20			<10
Si	20	20	24			8	<20			2
Sn	<6	<6	<6			<6	<10			<6
Sr	<10	<10	<10			<10	<10			<10
Ta	<2	<2	<2			<2	<2			<2
Ti	<2	<2	<2			<2	<10			<2
V	<6	<6	<6			<6	<6			<6
Zr	<6	<6	<6	–	–	<6	<10	–	–	<6

TABLE III

EM PUMP RESISTANCE AND PRESSURE MEASUREMENTS

Test Date	Temperatures °F Windings Front	Back	Cavity Stator	Duct	Coil Resist.-Ohms T_{1-2}	T_{2-3}	T_{3-1}	Resist. to Ground-Ohms	Pressure, psia Stator	Duct	Remarks
7/22	770	710	627	820	0.108	0.109	0.110	30 Meg(500V)	23	19	With 600°F NaK
7/28	1070	998	942	947	0.145	0.140	0.143	0.68 Meg(500V)	30	20	Design Point Cond.
7/30	980	895	830	1092	0.143	0.138	0.136	280K	24	22	Reduced Flow
8/1	900	855	780	840	0.129	0.128	0.130	480K	22	19	At Shut Down
8/4	107	104	-	-	0.59	0.57	0.57	1.5 Meg(50V)	9.1	10.0	After 1 Wk Shut Down (Loop Hot)
8/13	1064	992	900	1100	0.134	0.134	0.135	95K	23	22	Test at Design Point
8/18	1020	975	870	930	0.133	0.134	0.132	210K	22	20	At Start of Endurance Test
9/2	1020	972	865	932	0.143	0.145	0.142	160K	22	20	356 Hrs. of End.Test
10/20	1033	994	890	922	0.140	0.141	0.137	100K	21	20	1504 Hrs. Endur.
12/2	1015	970	860	925	0.136	0.141	0.137	380K	20	20	2537 Hrs.
12/23	945	905	820	915	0.135	0.134	0.134	500K	20	20	3034 Hrs.
12/30	84	84	86	87	0.53	0.52	0.52	2 Meg(50V)	9	10.5	After 1 Wk. Shut Down
2/16	1019	969	856	925	0.139	0.139	0.139	420K	20	19	4002 Hrs. Endur.
4/2	1010	960	870	917	0.137	0.137	0.137	180K	20	19	5106 Hrs. Endur.
5/4	1040	986	869	931	0.135	0.137	0.135	12.5K/350K (1)	-	-	5873 Hrs.
5/20	1024	976	866	923	0.130	0.130	0.131	670K	20	19	6256 Hrs.
7/20	1031	978	875	925	(2) 0.101	(2) 0.102	(2) 0.103	6.8K/305K (1)	20	19	7666 Hrs. (2)
10/30	1030	965	770	885	0.141	0.141	0.140	1.3 Meg	21	20	After Endur. Test
12/17	77	77	78	79	0.046	0.046	0.046	0.036 (Windings Grounded)	<10	10.7	After Shut Down (Resist. Data using Kelvin Bridge.)

(1) Double reading indicates value at shutdown and after "Hi-pot"
(2) Coil reading taken before start-up of pump after shutdown for facility maintenance

TABLE IV

SUMMARY OF FINAL PUMP PERFORMANCE DATA
WITH 60 Hz SINE WAVE POWER

TEST CONDITIONS (1)			TEST RESULTS				
Test No.	Line To Line Volts	K Flow Lb/Sec	Head Press Psi	Line Current AMPS	Power Input KW	Power Factor %	Efficiency %
FP-1	135.2	3.25	257.0	178.9	22.2	53.0	16.38
FP-2	135.1	3.75	187.0	174.5	20.8	51.0	14.68
FP-3	134.6	4.25	112.0	170.0	19.3	48.7	10.75
FP-3A	135.5	4.78(2)	27.0	166.0	17.6	45.2	3.19
FP-4	135.5	2.75	316.0	183.7	23.6	54.8	16.03
FP-5	135.4	2.58	334.0	184.8	24.0	55.5	15.63
FP-6	85.5	3.84(2)	16.0	108.5	8.0	49.8	3.34
FP-7	85.5	3.25	61.5	112.0	8.6	52.2	10.07
FP-8	85.3	2.50	112.0	116.9	9.4	54.3	13.02
FP-9	85.1	1.50	167.0	122.3	10.2	56.7	10.70
FP-10	85.2	0.60	200.0 206.5(3)	126.7	10.8	58.1	4.82
FP-11	45.1	0.75	53.0	67.2	3.1	58.7	5.63
FP-11A	45.2	0.38	57.3 60.5(3)	68.3	3.2	59.0	3.01
FP-12	45.2	1.20	44.5	66.0	3.0	57.9	7.76
FP-13	45.2	1.60	35.0	64.8	2.9	57.2	8.41
FP-14	45.4	2.00	22.1	63.4	2.8	56.4	6.83
FP-15	45.0	2.49(2)	5.5	61.4	2.7	55.4	2.25

(1) Pump Inlet Pressure = 8 psia
K Inlet Temp. = 1000°F ± 10°F
NaK Inlet Temp. = 800°F ± 10°F with 50°ΔT except 25°ΔT for 45 V. Tests

(2) Maximum Possible Flow

(3) Maximum Pressure - No Flow

TABLE V

SUMMARY OF PUMP PERFORMANCE DATA WITH POWER CONDITIONER FURNISHING QUASI-SQUARE WAVE POWER

TEST CONDITIONS (1)			TEST RESULTS				
Test No.	Line To Line Volts (2)	K Flow Lb/Sec	Head Press Psi	Line Current AMPS	Power Input KW	Power Factor %	Efficiency %
60 Hz							
CP-1	45.3	0.75	41.5	60.1	2.42	51.6	5.60
			56.5 (4)				
CP-1A	45.5*	0.75	20.0	41.4	1.36	41.7	4.78
CP-2	45.2	1.20	36.0	59.4	2.38	51.2	7.89
CP-3	45.2	1.60	28.0	58.6	2.35	51.3	8.30
CP-3A	45.5*	1.60	6.0	41.2	1.30	40.1	3.23
CP-3B	84.7*	1.60	47.0	75.2	4.26	38.7	7.68
CP-4	45.2	1.80	21.5	58.0	2.32	51.5	7.24
CP-5	46.0	2.32 (3)	6.5	57.6	2.30	50.2	2.87
CP-6	84.5	3.61 (3)	11.5	102.0	7.00	46.7	2.58
CP-7	86.5	3.25	48.0	106.0	7.70	48.5	8.82
CP-8	85.8	2.50	88.5	108.0	8.00	49.9	12.05
CP-9	84.5	1.50	131.5	110.0	8.40	52.2	10.24
CP-10	84.2	0.75	148.0	111.2	8.50	52.5	5.67
			156.0 (4)				
CP-11	134.0	2.30	281.0	170.8	20.20	51.0	14.00
CP-11A	135.0*	2.30	105.0	119.2	10.56	37.8	9.94
CP-12	134.5	2.75	246.0	168.4	19.60	50.0	15.02
CP-13	136.0	3.30	192.0	167.6	19.20	48.7	14.38
CP-14	137.0	3.78	143.0	166.0	18.40	46.8	12.79
CP-15	135.5	4.25	75.0	162.0	17.20	45.3	8.08
CP-15A	136.5	4.70 (3)	25.0	161.6	16.40	43.0	3.12
CP-14SS	131.7	3.25	240.0	174.6	21.00	52.8	16.18
	(Shop Power-Sine Wave)						
CP-14SP	143.8	3.19	240.0	179.2	21.80	48.8	15.28
	(Power Cond.-Quasi Sq. Wave-3 Capacitors)						
45 Hz							
CP-16	45.7**	0.75	32.0	54.8	1.90	43.9	5.53
CP-16A	45.0*	0.75	30.0	51.0	1.63	40.9	6.05
CP-17	45.0**	1.20	24.0	53.2	1.83	43.2	6.80
CP-17A	85.2**	1.20	97.0	100.8	6.20	41.7	8.18
CP-18A	45.5**	1.48	18.7	54.0	1.82	43.0	6.96
CP-19	45.5**	1.80	14.0	53.0	1.78	42.7	6.18
CP-19A	85.2**	1.90	71.0	100.0	6.08	41.2	9.65
CP-19B	45.0*	2.00	5.0	50.7	1.57	39.8	2.80
CP-19C	84.0*	2.00	66.0	93.4	6.54	48.2	8.79
CP-20	46.0**	2.01 (3)	5.0	53.4	1.78	41.9	2.47

TABLE V (CONTINUED)

TEST CONDITIONS (1)			TEST RESULTS				
Test No.	Line To Line Volts (2)	K Flow Lb/Sec	Head Press Psi	Line Current AMPS	Power Input KW	Power Factor %	Efficiency %
25 Hz							
CP-8A	84.0*	2.00	54.0	141.6	6.90	33.5	6.81
CP-9A	84.0**	1.50	110.0	139.0	7.18	35.5	10.01
CP-21	45.0	0.83	70.0 87.0 (4)	89.0	3.15	45.5	8.03
CP-21A	45.0**	0.83	62.0	81.0	2.70	42.8	8.30
CP-21B	45.5*	0.83	51.0	75.4	2.15	36.2	8.58
CP-22	45.0	1.20	57.0	89.4	3.00	43.1	9.93
CP-22A	45.0**	1.23	42.0	81.0	2.53	40.1	8.90
CP-22B	45.0	1.20	58.0	89.0	3.01	43.4	10.01
CP-23	45.5	1.60	36.0	91.0	2.95	41.2	8.54
CP-24	45.5	1.80	22.0	91.3	2.94	41.0	5.84
CP-25	46.0	2.07 (3)	8.0	92.4	2.90	39.5	2.41
CP-25A	45.6*	1.94 (3)	5.0	77.2	2.03	33.3	2.07

(1) Pump Inlet Pressure = 8 psia
K Inlet Temp. = 1000°F ± 10°F
NaK Inlet Temp. = 800°F ± 10°F with 50°ΔT except 25°ΔT for 45 V. Tests

(2) Three Capacitors on DC Line Input Except as Noted

(3) Maximum Possible Flow

(4) Maximum Pressure - No Flow

*One Capacitor
**Two Capacitors